Vol. IV

TRANSCRIPT OF RECORD

Supreme Court of the United States

OCTOBER TERM, 1930

No. 630

DEFOREST RADIO COMPANY, PETITIONER,

vs.

GENERAL ELECTRIC COMPANY

ON WRIT OF CERTIORARI TO THE UNITED STATES CIRCUIT COURT OF APPEALS FOR THE THIRD CIRCUIT

PETITION FOR CERTIORARI FILED JANUARY 8, 1931

CERTIORARI GRANTED FEBRUARY 25, 1931

(35,552)

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PLAINTIFF'S EXHIBIT No. 1.

Oct. 20, 1925. 1,558,436

I. LANGMUIR

ELECTRICAL DISCHARGE APPARATUS AND PROCESS OF PREPARING AND USING THE SAME

Original Filed Oct. 16, 1913

Fig. 1.

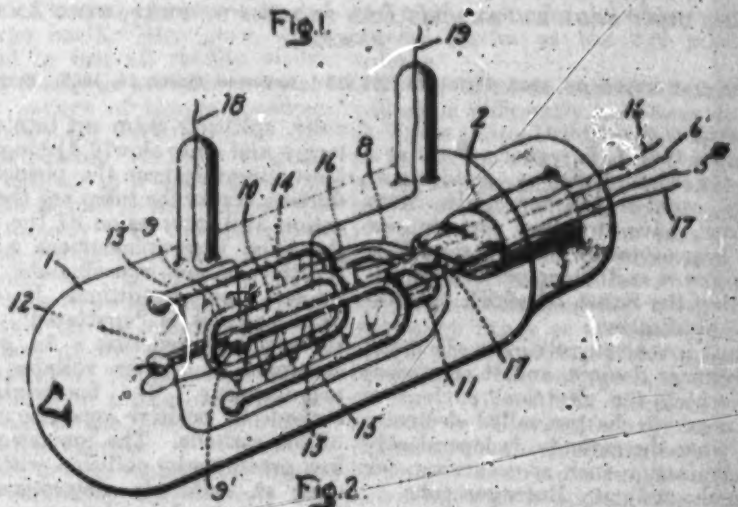


Fig. 2.

Fig. 3.

Fig. 4.

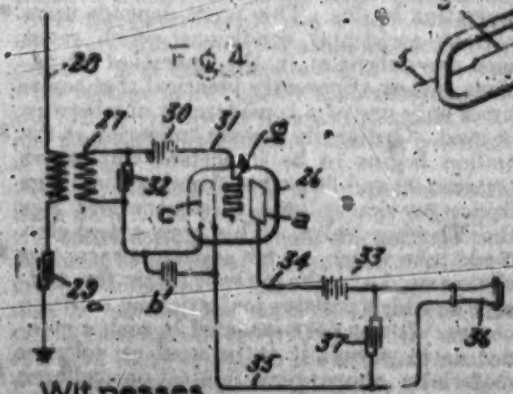
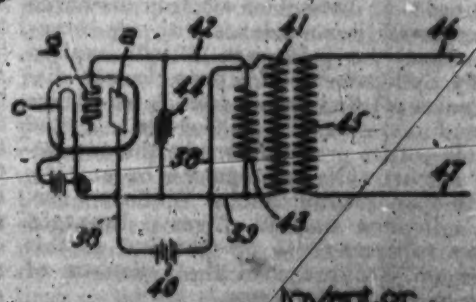


Fig. 5.



Witnesses

J. Ellis Glover

Inventor
Irving Langmuir
by Albert G. Davis
His Attorney

Patented Oct. 20, 1925. 1,558,436

UNITED STATES PATENT OFFICE.

IRVING LANGMUIR, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

ELECTRICAL DISCHARGE APPARATUS AND PROCESS OF PREPARING AND USING THE SAME.

Application filed October 16, 1913. Serial No. 795,610. Renewed March 14, 1916. Serial No. 84,242.

To all whom it may concern:

Be it known that I, IRVING LANGMUIR, a citizen of the United States, residing at Schenectady, county of Schenectady, State of New York, have invented certain new and useful Improvements in Electrical Discharge Apparatus and Processes of Preparing and Using the Same, of which the following is a specification.

The present invention relates to electrical vacuum discharge devices, and it comprises devices in which the electrical current is carried by negative charges called electrons, emanating from the cathode, independently of gaseous ionization such as occurring, for example, in the ordinary Roentgen tube.

My present invention comprises improvements in electron-discharge apparatus which make possible a high load capacity and operation with the highest voltages but the invention is also applicable and useful for moderate loads and moderate voltages. The novel features of my invention will be pointed out with greater particularity in the appended claims.

Figs. 1 and 2 of the accompanying drawings, Fig. 2 being a partial view, illustrate two types of discharge devices embodying my invention; Fig. 3 is a fragmental view showing a cathode construction, and Figs. 4 and 5 are diagrams of electrical systems illustrating certain applications of my electron discharge tubes.

In order to distinguish electron discharge devices made in accordance with my invention from the prior art, I will explain briefly the character of a pure electron discharge as distinguished from a discharge through ionized gas. In a Geissler tube, and in a Roentgen or Crookes tube the conduction of current is accompanied by and depends upon gas ionization. Without a certain minimum amount of gas a Roentgen X-ray tube ceases to operate and as this minimum is approached the resistance of the tube steadily increases.

The passage of an electric current across a tube ordinarily involves the movement of negative charges called electrons which, under the influence of the impressed voltage, pass from the cathode to the anode through the vacuous space. If these electrons when moving above a certain velocity collide with gas molecules they tend to ionize the molecules, splitting them up into electrons and larger and more slowly moving ions. Under these circumstances the phenomena of conduction across the tubes are the result of the action and interaction of the electrons and the ions; these phenomena are in general erratic and non-reproducible. The cathode under these conditions is disintegrated, technically it is "sputtered", which causes its rapid destruction. As gas ionization continues at higher voltages a blue glow may appear. The bombardment of the cathode by positive ions also causes heating of the cathode. The ionization of gases at low pressures by collision with electrons occurs at definitely determinable voltages, these voltages being known as the ionization voltages. These voltages are different for different gases. In the case of gases such as nitrogen, hydrogen, oxygen, argon, helium and neon, they are of the order of magnitude of fifteen to twenty-five volts.

The phenomena above described as being characteristic of devices involving gas ionization are taken advantage of in an incandescent cathode device with three electrodes known as the "Audion." This device has been used as a receiver for radio-telegraphy and depends in its operation upon the rapid change of the discharge current when gas ionization begins. This point depends upon various accidental conditions which cause such irregularities in the operation of various devices apparently identical that sometimes only one of a considerable number can be used. Ordinarily the gas ionization in the audion begins to be important somewhere between 20 and 30 volts. Another discharge device previously used to some extent was the Fleming valve. This was a two-electrode tube which, so far as I am aware, was always used at voltages well below the voltages at which positive ionization by collision occurs. It was not evacuated in such a manner as to permit it to be used at voltages materially above these ionization voltages without manifesting substantial positive ionization effects. No prior hot cathode devices are known to me operating with currents as great as about 5 milliamperes with voltages as high as about 200 volts; indeed no prior discharge devices are known to me operating in a practically stable manner and without substantial positive ionization

effects with currents as great as about one-tenth of a milliampere with voltages as high as about forty volts.

In devices made in accordance with my invention gas ionization is either entirely absent or is negligible and a discharge takes place which is distinct in its characteristics from the described discharge taking place in an ionized gas. The cathode is not heated by the discharge itself. Blue glow, glass fluorescence and in fact all readily visible indications of a discharge are ordinarily absent. In most devices of simple construction which embody my invention, the discharge current passing through a given space with the cathode at a sufficiently high temperature with respect to the voltages employed, varies directly with the 3/2 power of the impressed voltages. This 3/2 power law can be readily derived mathematically for a tube in which there is substantially no positive ionization on the assumption that the whole surface of the cathode is at a uniform potential, that the electrons escape from the cathode with negligible velocities and that the walls of the tube do not carry appreciable electric charges.

In most simple devices embodying my invention, these conditions are so well fulfilled that the current does vary in proportion to the 3/2 power of the voltage over wide ranges of voltage above the ionizing voltages. This means that if the logarithm of the current is plotted against the logarithm of the voltage, the resulting plot is a straight line whose slope is 3/2. Or, in many cases it is more convenient to make use of the equivalent relation, that the 2/3 power of the current plotted as ordinates against the anode voltages as abscissæ gives a straight line.

In devices in which there is substantial positive ionization, on the other hand, even when the pressures of gas are so low that only very small currents could be carried by positive ions, the currents begin to increase with voltage more rapidly than according to the 3/2 power law as soon as the anode voltage materially exceeds the ionizing potential of the gas.

In devices embodying my invention which have more than two electrodes, or with special constructions, as where the cathode is a filament, so long that it cannot be considered an equi-potential surface, the 3/2 power law may be more or less masked. However, the effects thus introduced will be readily understood by those skilled in the art, and appropriate methods of identifying the pure electron discharge can easily be found corresponding to the special construction. For example, when such tubes have more than two electrodes and the temperature of the cathode is sufficiently high with respect to the voltages employed, the discharge will usually be characterised by a linear relation between the 2/3 power of the total electron current from the cathode and the voltage applied to any other electrode, the remaining electrodes being kept at constant potential. Another test that can often be made with a three electrode tube is to connect the grid directly to the anode, or to the negative end of the cathode, and observe whether the current varies as the 3/2 power of the voltage.

If for a given cathode temperature the voltage is sufficiently high to cause all of the electrons emitted or liberated at the cathode to be drawn away, then a further increase in voltage produces substantially no change in the current. The current thus determined is called the saturation current, and the range of operation in which the current is substantially independent of the voltage or approaches this condition may be called the saturation range or more briefly designated merely as saturation. If for a given cathode temperature the voltage is not high enough to cause all of the electrons which are emitted or liberated at the cathode to be drawn away, the operation occurs in a range below the saturation range. Operation in this range may be spoken of as operation below saturation.

A change in the temperature of the cathode in a hot cathode device embodying my invention will produce no change in the discharge when the operation is below saturation, even though the ionization voltage is materially exceeded. That is, the current-voltage curve is not changed by a change in the cathode temperature under such conditions.

The discharge in devices embodying my invention is practically independent of the pressure when the pressure is below a certain value which depends upon the size and shape of the device and upon the current and voltage of the discharge.

As distinguished from discharges in the presence of positive ionization, the pure electron discharge is characterised by regularity and reproducibility with given conditions. In a device in which the conduction of current is purely electronic, and the effect of positive ions is negligible, the conduction of current is governed, over a certain range, on the one hand by the effect of the impressed voltage, which tends to propel the electrons across the vacuous space, and on the other hand by the mutual propulsion of the electrons in the space, which tends to limit or inhibit the current. This last mentioned phenomenon, the current limiting effect of the electric field of the electrons on each other, termed the "space charge effect," is discussed and analyzed by me in a paper read before the Physical Society on October 18, 1913, which was abstracted in the Physi-

cal Review for November, 1913, and published in full in the Physical Review for December, 1913, and again published in somewhat modified form in the Physikalische Zeitschrift for April 1, and May 15, 1914. It is the basis of the 3/2 power law referred to herein.

The geometric proportions of the device also affect the amount of current which will pass with a given voltage, but as these conditions remain fixed for a given device they may be represented by a constant in an equation expressing the relation between the current and the voltage.

As stated above, the current (I) in the particular device described herein, when operating below saturation, will vary with the 3/2 power of the voltage (V), the equation being:

$$I = aV^{3/2}, \text{ (a being a constant)}$$

As is well known, if we produce a logarithmic graph of any equation in which one variable of the equation varies as a power of the other variable, as for example, an equation of the general form $y=x^n$, (as by plotting logarithms of x as abscissæ and logarithms of y as ordinates) we find that the graph is a straight line. Hence the relation between current and voltage in a device operating below saturation and by pure electronic conduction independent of gas ionization may be expressed by the statement that when with a sufficient electron emission the logarithms of the current values transmitted between cathode and anode are plotted as ordinates against the logarithms of the respective voltages impressed between cathode and anode as abscissæ, the slope of the line obtained does not ordinarily increase for increasing voltage values over a working range of voltages extending materially above the ionization voltages.

A substantial amount of positive ionization ordinarily causes the logarithmic plot of the current with respect to the voltage to bend upwardly and away from the 3/2 power line when the ionizing voltage is materially exceeded. The absence of a bend in the logarithmic plot at voltages somewhat above the ionization voltage is ordinarily a reliable indication that the tube is a pure electron discharge tube, though saturation complete or partial at voltages somewhat greater than the ionization voltages may prevent such a bend in the plot of an ionizing tube.

As above indicated, one of the indications of positive ionization is the occurrence of erratic readings in measuring devices connected in circuit with an electron discharge device under observation. Such erratic readings, of course, will produce a sudden change or discontinuity in the logarithmic graph plotted as above described, and any such irregularities will be more manifest when observed as deviations from a straight line than when the readings are plotted directly.

The effect of positive ionization upon the magnitude of the discharge is especially marked in that region of operation where the current is limited by the space charge effect already discussed, and changes in curvature of the discharge characteristics may occur as indicated unaccompanied by any visible evidence of ionization such as blue glow or the like. At saturation on the other hand, the discharge is ordinarily much less sensitive, and in fact the discharge may actually exhibit marked blue glow effects along with a flat or straight saturation curve.

Devices made in accordance with my invention may be used for various technical purposes, such as relaying and detecting currents, producing oscillations and rectifying alternating currents, and such devices may be made which will operate without substantial positive ionization at voltages far above the ionization voltages with currents thousands of times greater than the currents at which the devices of the prior art were operable without substantial positive ionization. Devices made and operated in accordance with my invention are capable of transmitting currents materially exceeding one-tenth of a milliampere without causing positive ionization to take any essential part in the operation of the device, though the voltage is materially above the ionization voltages.

Before describing the method of preparing my new type of apparatus, I will describe the structure of the apparatus illustrated by Figs. 1 to 3.

As shown in Fig. 1 the various parts of the apparatus may be mounted in a tube, or envelope 1, upon a pedestal 2, similar to the mount used in incandescent lamps. The cathode 3 is centrally located and may consist of a short straight filament not shown in Fig. 1, but indicated by the position of terminals 5, 6, and shown plainly in Fig. 3. The cathode shown in Fig. 2 consists of a V-shaped conductor. Either form may be used, the particular form of cathode being ordinarily determined by convenience of construction. Preferably the cathode conductor is held taut by a spring 7 to avoid contact of the cathode conductor with the grid by sagging when the metal is expanded at a high temperature. The filament 3 is mounted between two oppositely disposed supports, 9, 9', in this case constituting a closed loop, which may consist of insulating material, such as glass or quartz, but in some cases may to advantage consist of metal. Upon this frame-work is wound a discharge-varying conductor 10, ordinarily called a grid. The turns of the wire are closely adjacent to each other and are also very closely

adjacent to but are out of contact with the incandescent cathode. By means of this grid 10 potential may be applied to exert a static control upon the movements of the electrons. A negative potential applied on the grid reduces the flow of current from cathode to anode in proportion to the degree of negative charge. A positive grid potential assists and directs the flow of current from cathode to anode in proportion to the degree of its charge.

The supporting framework for the cathode and grid is attached to a rod 11, mounted upon the stem of the tube. Adjacent to the cathode and grid is the anode 12 which in the present case has been indicated as consisting of a wire strung in a zig-zag manner over hooks 13 upon fork-shaped supports 14 and 15, but it is not necessary that it should assume this particular form. Both anode and grid preferably consist of tungsten, but other refractory metals may be used. By constituting the anode a continuous conductor it can be conveniently heated by passage of current during evacuation of the device and for this purpose is attached to leading-in conductors 16 and 17. The grid is indicated in Fig. 1 as being attached to leading-in conductors 18 and 19 at opposite ends, although but one terminal is ordinarily necessary.

In some cases it is desirable to use a plate-shaped anode; Fig. 2 illustrates such an arrangement suitable particularly for rectifying alternating current. The tube itself and other extraneous parts have not been shown in Fig. 2, as they are similar to Fig. 1. The cathode construction has already been referred to and the anodes 20 and 21 also preferably consist of tungsten and may be connected electrically with each other. Current connections are made by conductors 22, 23, the supports 24, 25 being merely indicated. It will be noted that both in Figure 1 and Figure 2 the electrons are afforded a short and direct path from the cathode to the anode and that this path is so related to the position of the walls of the tube as to minimize the tendency for electrons to pass to the walls of the tube. In such a tube electron bombardment of the walls of the tube is avoided, together with the heating of such walls and the secondary emission of electrons therefrom which said bombardment causes. The energy of the discharge is delivered mainly, or entirely, at the anode, anodes, or upon other interior members instead of at the walls of the tube.

For the evacuation of the device the glass walls of the tube are carefully heated to as high a temperature as the glass will stand without softening and in general the most approved methods of incandescent lamp exhaust are used. The evacuation of the tube preferably while still heated is carried out by means of a suitable evacuating means, for example, a Gaede molecular pump, which removes vapors as well as gases. Chemical evacuating means such as electrically vaporized calcium or magnesium may also be used. Either before or during the evacuation the anodes may be heated, especially when the anodes are to be run at elevated temperature during the normal operation of the device. In this case the temperature is preferably carried close to brilliant incandescence. In the case of the structure shown in Fig. 1, the heating may take place by passing an electrical current through the wire 12. The heating, especially of solid anodes such as shown in Figure 2, may take place in a suitable vacuum furnace, the temperature preferably being raised to 2,500° C. or even higher. Bombardment is a very effective means of removing occluded gas from anodes.

The bombardment is carried out when the evacuation has proceeded to a high degree by applying a potential between the cathode 3 and the anode 12, Fig. 1, the value of which depends upon the character of the device. Care should be taken to use a voltage below that at which a blue glow appears as this indicates harmful gas ionization, and as already pointed out, sputtering and disintegration of the cathode accompanies or closely follows the blue glow phenomenon. The pump should be constantly operated to remove the gas. After the removal of the gas thus driven out the voltage impressed between the cathode and the anode, or anodes, as the case may be, is increased thereby driving out more gas. This process is continued step by step with a progressively higher voltage, the final voltage depending upon the character of the apparatus. In most cases the final voltage should be materially higher than the voltage at which the device is to be used in actual service. However, in the case of devices that use exceedingly high voltages, such as 50,000 volts or even higher, substantially all the gas may be removed from the anode without resorting to voltages higher than the normal operating voltage. In the case of a plate-shaped anode which cannot be readily heated by passage of current, the discharge voltage may be chosen great enough to convey sufficient energy to the anode to raise its temperature to redness or even higher, when the device is to be used with a discharge current adapted to heat the anodes.

After the metal has been freed from occluded gas reabsorption of gas will not readily take place even though it is exposed to the air or other gases. For example, anodes thus treated may be removed to other apparatus which then may be evac-

nated with less electron bombardment of the anode or anodes.

The evacuation of the device should be preferably carried to a pressure as low as a few hundredths of a micron, or even lower, but no definite limits can be assigned. The residual gas pressure should be below the value at which ionization by collision will take place at the given working voltage and current, with its accompanying phenomena of blue glow, disintegration of the cathode, and so forth. When the cathode and anode are located in close proximity and the discharge confined to the region between the same, the permissible pressure is higher than when the cathode and anode are at some distance. It is also true that when the anode has been carefully freed from gas, residual free gas, even if present in a sufficient amount to cause some gas ionization when the apparatus is first started, does little harm, as it is quickly removed by the gas clean-up effect when the device is operated.

Electron discharge apparatus thus provided with a gas-free pretreated anode or anodes, may be constructed to handle currents at a very high voltage by proper mechanical design of the parts subjected to static strains, suitable proportioning of the parts and so forth as described, for example, in my application Serial No. 795,609 filed concurrently herewith upon which Patent 1,273,783 was granted on July 23, 1918.

The asymmetric conductivity existing between the heated and unheated electrodes of a device of the character described may be utilized for various technical purposes. Reference has already been made to the rectification of current. As shown in Fig. 4 an electron discharge tube may be used for detecting electromagnetic waves in radio-telegraphy. As shown in this Fig. 4 the grid g and heated cathode c of an electron discharge tube 26 are connected respectively to the terminals of the secondary of a transformer 27, the primary of which is included in the antenna circuit 28. The antenna is grounded through a condenser 29 in the usual manner. The cathode c is heated by a local source of energy, as battery b. A battery 30 in the grid circuit 31 has its negative terminal connected to the grid g. A condenser 32 shunts the secondary of the loosely coupled transformer 27. The inductance of the transformer and the capacity of the condenser are adjusted to make the receiving circuits resonant to the frequency of the oscillations to be received. The oscillations set up by the incoming signals are superimposed upon the negative grid potential and causes a variation of current transmitted between cathode c and anode a by a local source of energy such as a battery 33 included in the local or plate circuit 34, 35, of the discharge tube. This circuit is connected to an ordinary telephone receiver 36, preferably shunted by means of a condenser 37, whereby the signals are detected.

Fig. 5 illustrates how an electron discharge tube may be used in a system for producing alternating current from direct current. The anode a and cathode c are connected respectively to conductors 38, 39, one of which includes a local source of energy, such as a battery 40. The terminals of these conductors are connected to an inductive coil 41. The cathode and grid g are also connected respectively by conductors 39 and 42 to a second inductive coil 43 which may be in a variable inductive relation to the coil 41. As soon as a flow of current starts in the plate circuit 38, 39, current is induced in the coil 43 of the grid circuit 39, 42. When by reason of this current the grid becomes negatively electrified, the flow of current in the plate circuit is reduced, and as the plate current decreases the grid electrification changes to positive, which again allows the current in the plate circuit to increase. These changes take place with a frequency depending on the electrical characteristics of the circuits. Across the grid circuit 39, 42, of the discharge tube, in some cases is connected a condenser 44, the capacity of which may be varied to control the frequency of the oscillations set up by the system. The oscillations may be transformed to higher or lower voltage by a transformer coil 45 to the terminals of which are connected transmitting conductors 46, 47. The system shown in Fig. 5 is described and claimed in a copending application, Serial No. 797,087, filed October 29, 1913.

Residual gas left in a tube when it is sealed off or occluded gas driven off from the inner wall of the tube, or from the electrodes, during the use of the tubes, varies in pressure from time to time according to the conditions of operation of the tube and may produce irregularities in the discharge when operating in the saturation region as well as when operating below saturation. The irregularities below saturation are due mainly to the disturbing effect of the resulting positive ions upon the space charge. The irregularities in the saturation region are due to changes in the rate of emission or liberation of electrons at the cathode. It is obvious that the advantages of stable and reproducible operation and freedom from destructive bombardment of the cathode by positive ions, which advantages are severally or collectively to be secured by the means hereinabove described, are not limited to operation below saturation but are also important in operation in the saturation region.

The positive ionization herein referred to is that positive ionization which occurs as the result of collisions between electrons and gas molecules in the space between the electrodes and causes, as by producing changes in space charge, unstable and non-reproducible operation.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. A discharge tube having electrodes at least one of which is adapted to emit electrons, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that the governing or limiting action on the space current due to the electric field of said electrons is substantially unaffected by positive ionization and by secondary electron emission from the walls of the tube.

2. A discharge tube having a cathode adapted to emit electrons and an anode adapted to receive said emitted electrons, the tube walls being fashioned or shaped to permit the direct passage of a useful proportion of said electrons from cathode to anode, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that the space current is governed or limited by the electric field of said electrons substantially unaffected by positive ionization.

3. A discharge tube having electrodes at least one of which is adapted to emit electrons, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that in that range the space current is governed by the combined effect of the electric field of said electrons and the potentials applied to said electrodes, the governing or limiting of the current being substantially unaffected by positive ionization and by secondary electron emission from the walls of the tube.

4. A discharge device comprising a tube and electrodes therein one of which is adapted to emit electrons, the degree of evacuation and the relation of the parts of the device being such that the device is capable of being so operated, when voltages materially higher than ionization voltages are impressed upon electrodes of the device and when the electron emission has any value such that the space current is below the saturation region at such voltages, that the slope of the line obtained by plotting the logarithms of values of said current as ordinates against the logarithms of the corresponding values of said impressed voltages as abscissæ shows no increase for increasing voltage values.

5. A discharge device comprising a tube and electrodes therein one of which is adapted to emit electrons, the degree of evacuation and the relation of the parts of the device being such that the device is capable of being so operated, when voltages materially higher than ionization voltages are impressed on electrodes of the device and when the electron emission has any value such that the space current is below the saturation region at such voltages, that the line obtained by plotting the logarithms of any values of said current below the saturation region as ordinates against the logarithms of the corresponding values of said impressed voltages as abscissæ is straight and continuous.

6. A discharge tube having electrodes at least one of which is adapted to emit electrons, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated, when voltages materially higher than ionization voltages are impressed on electrodes of the tube and when the electron emission has any value such that the space current is below the saturation region at such voltages, that said current varies as the three halves power of said impressed voltages.

7. A discharge device comprising a tube and electrodes therein one of which is an electron emitting cathode, the degree of evacuation of said device and the relation of the parts of the device being such that the device is capable of being so operated, when voltages materially higher than ionization voltages are impressed on electrodes of the device and when the electron emission is such that the space current is below the saturation region at such voltages, that said current is substantially independent of the cathode temperature and unaffected by secondary electron emission from the walls of the tube.

8. A discharge tube having electrodes at least one of which is adapted to emit electrons, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that the space current is governed or limited by the combined effect of the electric field of said electrons and the potentials applied to said electrodes, substantially unaffected by positive ionization, the heating effect in the tube due to said current occurring substantially only at one or more of said electrodes.

9. A discharge tube having a cathode adapted to emit electrons, an anode adapted to receive electrons and tube walls fashioned or shaped so as to permit the free passage

of a useful proportion of said electrons from cathode to anode, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of operation with stable and reproducible results substantially unaffected by positive ionization, with currents of at least 5 milliamperes and with voltages of at least 200 volts.

10. An electrical discharge device comprising a gas-tight envelope, an electron-emitting cathode, a cooperating anode, and a discharge-varying conductor, the space in said envelope being evacuated to below the pressure at which deleterious gas ionization takes place, constituting a device in which the current passed when operated below saturation and over a working range of voltage materially above the ionization voltages is controlled by space charge substantially unaffected by positive ionization.

11. A high vacuum electron discharge device comprising an envelope, an incandescent cathode, and an anode, the space in said envelope being evacuated to such degree that the passage of current produces no appreciable positive ionization when the impressed voltage is as high as 200 volts

12. An electrical discharge device, comprising a gas-tight envelope, an electron emitting cathode, an anode deprived of ionizable gas and a discharge controlling conductor, the space in the envelope being evacuated to a pressure not substantially in excess of a few hundred thousandths of a millimeter of mercury, said device being characterized by the fact that when operated below saturation and materially above the ionization voltages, the current is controlled by space charge substantially unaffected by positive ionization.

13. An electrical discharge device comprising a gas-tight envelope, an electron emitting cathode, a cooperating anode, the space and materials in said envelope being sufficiently free of gas so that substantially no positive ionization occurs when the impressed voltage is as high as 60 volts, and the current over a working range of voltage up to 90 volts varies with the 3/2 power of the impressed voltage.

14. An electrical discharge device comprising a gas-tight envelope, a cathode adapted to be heated to incandescence, an anode from which substantially no ionizable gas can be evolved at operating voltages up to 100 volts with currents up to 1 milliampere, the envelope so shaped and the electrodes so positioned as to substantially avoid secondary electron emission from the wall of the envelope, the space in said envelope being evacuated to a pressure not in substantial excess of a few hundred thousandths of a millimeter of mercury.

15. A device comprising a gas-tight envelope, a cathode adapted to be heated to incandescence, an anode from which no ionizable gas can be evolved at operating voltages up to about 200 volts with operating currents up to about five milliamperes, the space in said envelope being evacuated at a pressure not in substantial excess of a few hundred thousandths of a millimeter of mercury, said device being characterized by the fact that with currents up to about five milliamperes at voltages up to about 200 volts, evidences of positive ionization are substantially absent and the current over a working range below saturation varies with the 3/2 power of the voltage.

16. An electrical discharge device comprising a sealed envelope, an incandescent cathode, and a tungsten anode, said anode deprived of ionizable gas disengageable by electron bombardment, and the space in said envelope being evacuated to a sufficiently low pressure so that current flow produces substantially no phenomena of positive ionization when the impressed voltage is as high as 100 volts and the current is as large as 1 milliampere, and the energy of the discharge is delivered mainly upon said anode.

17. An electron discharge apparatus comprising an envelope, an electron emitting cathode, and an anode, said anode being free of gas disengageable by electron bombardment and said envelope being sufficiently free of gas, so that conduction of current can take place in the evacuated space independently of gas ionization at voltages materially above the ionizing voltages with currents of more than one-tenth of a milliampere, and with the energy of the discharge delivered mainly at said anode.

18. An electrical discharge device comprising a sealed envelope, a cathode, means for producing emission of electrons at said cathode independently of the operating voltage, an anode, and discharge varying means independent of the cathode and anode, said device being freed from gas to such extent that the same is operable to transmit current at an impressed voltage at least as high as about 200 volts without evidences of substantial positive ionization.

19. An electrical discharge device comprising a sealed envelope, an incandescent cathode, an anode and discharge-varying means independent of the cathode and anode, the gas residues in said device being so small that the conduction of current is stable and reproducible over a range of voltage materially above the ionization voltages with currents in excess of one milliampere and with the energy of the discharge delivered mainly upon electrodes.

20. An electrical device comprising the combination of a sealed evacuated envelope, a cathode adapted to be independently heated, and an anode within said envelope,

an external circuit connected to said electrodes, and a source of electro-motive force applied to said circuit, the degree of vacuity and the electron emission of the cathode being so related to the potential of said source that the flow of current over a range of voltage materially above the ionization voltage is governed by the electric field of the electrons in the vacuous space and the potential applied to said electrodes, operatively independent of gas ionization.

21. Apparatus for controlling an electric current comprising a vacuum tube, an anode and an electron emitting cathode in the circuit of said current and within said tube, the degree of evacuation of the tube and the relation of its parts being such that for voltages materially above ionization voltage the current is governed or limited by the electric field of the electrons in said tube substantially unaffected by positive ionization, and a third electrode in said tube by which an auxiliary controlling electromotive force may be superposed to modify the effect of said electric field and control said current in a stable and reproducible manner.

22. The method of controlling an electric current in one circuit by an electromotive force in another circuit which consists in causing said current at voltages materially above ionization voltages to pass as a discharge across a vacuous space between an electron emitting cathode and an anode, maintaining a high vacuum in said space, governing or limiting the current by a space charge effect in said space substantially unaffected by positive ionization, and superimposing the effect of said electromotive force on said space charge effect to control said current in a stable and reproducible manner.

23. A discharge device comprising a tube and electrodes therein, one of which is a cathode, the discharge passing in the main directly between electrodes, the degree of evacuation and the relation of the parts of the device being such that the device is capable of being so operated below saturation and at voltages materially higher than the ionization voltages, that the slope or location of the logarithmic line of current with respect to voltage is not changed by changes in the temperature of the cathode.

24. A discharge device comprising a tube and electrodes therein, one of which is a cathode adapted to be heated and to emit electrons thereby, the discharge passing directly between electrodes, the degree of evacuation and the relation of the parts of the device being such that the device is capable of being so operated below saturation and at voltages materially higher than the ionization voltage, that the plot of the current against the voltage is not changed with changes in the temperature of the cathode.

25. A discharge device comprising a sealed off envelope having therein a cathode adapted to be heated independently of the discharge and to deliver electrons thereby, and an anode, the inner wall of the envelope and the electrodes being sufficiently free of occluded gas, and the free gas within the envelope being such, so that the finished device is capable of sustained operation below saturation in a stable and reproducible manner with currents of more than one milliampere at voltages materially higher than the ionization voltages and with the energy of the discharge delivered mainly at an electrode or electrodes.

26. A discharge device comprising a sealed off envelope and electrodes therein, the envelope being shaped and the electrodes located so that the energy of the discharge is delivered mainly upon one or more of the electrodes, the inner wall of the envelope and electrodes being so free from occluded gas and the pressure in the tube being sufficiently low, with respect to the spacing of the electrodes and the energy of the discharge, so that the device is capable of passing a sustained discharge of one tenth of a milliampere at forty volts, without developing any substantial positive ionization effects.

27. A discharge device comprising a sealed off envelope and electrodes therein, one of which is a cathode adapted to be heated independently of the discharge and to emit electrons thereby, the inner wall of the envelope and the electrodes being so free from occluded gas that the device is capable of passing a sustained discharge of one milliampere at fifty volts with the energy of the discharge delivered mainly at an electrode or at electrodes without liberating any substantial amount of gas into the space within the envelope.

28. A discharge device comprising a sealed-off envelope and electrodes therein, one of which is a cathode adapted to be heated independently of the discharge and to emit electrons thereby, the inner wall of the envelope and the electrodes being so free from occluded gas that the device is capable of passing a sustained discharge of two milliamperes at one hundred volts with the energy of the discharge delivered mainly at an electrode or at electrodes without liberating any substantial amount of gas into the space within the envelope.

29. An electrical discharge device comprising a gas-tight envelope, a cathode adapted to be heated to incandescence, an anode from which substantially no ionizable gas can be evolved at operating voltages up to forty volts with currents up to one-tenth milliampere, the envelope so shaped and the electrodes so positioned as to substantially avoid secondary electron emission from the wall of the envelope, the space in said en-

velope being evacuated to a pressure not in substantial excess of a few hundred thousandths of a millimeter of mercury.

30. In the process of producing a discharge device, removing the occluded gas from the interior surface of the envelope thereof and from the electrodes to such an extent that the finished sealed-off device will operate, without liberating any substantial amount of gas into the space within the envelope, at voltages materially above the ionization voltage with currents greater than one milliampere and with substantially all the energy of the discharge delivered to an anode or anodes.

31. In the process of producing a hot cathode discharge device, treating the interior surface of the envelope and the operating parts to liberate therefrom occluded gas, and removing from the envelope gas liberated by said treatment and free gas originally contained therein, continuing these operations until the occluded and original free gas is so thoroughly removed as to enable the finished sealed-off device to operate below saturation in a stable and reproducible manner at a voltage above fifty volts and with a current greater than one milliampere and with the energy of the discharge delivered mainly at one or more anodes.

32. The process of producing a discharge device which consists in treating the envelope and enclosed parts thereof to liberate gas therefrom and removing from the envelope gas which is thereby liberated and free gas originally contained in the envelope, the treatment being sufficiently powerful and being sufficiently prolonged and the removal of the liberated and original free gas from the envelope being sufficiently thorough, so that the finished sealed-off device is capable of sustained operation substantially without positive ionization at voltages as high as one hundred volts with currents as great as one milliampere and with substantially the entire energy of the discharge delivered upon the anode or anodes of the device.

In witness whereof, I have hereunto set my hand this 15th day of October 1913.

IRVING LANGMUIR.

PLAINTIFF'S EXHIBIT No. 2.

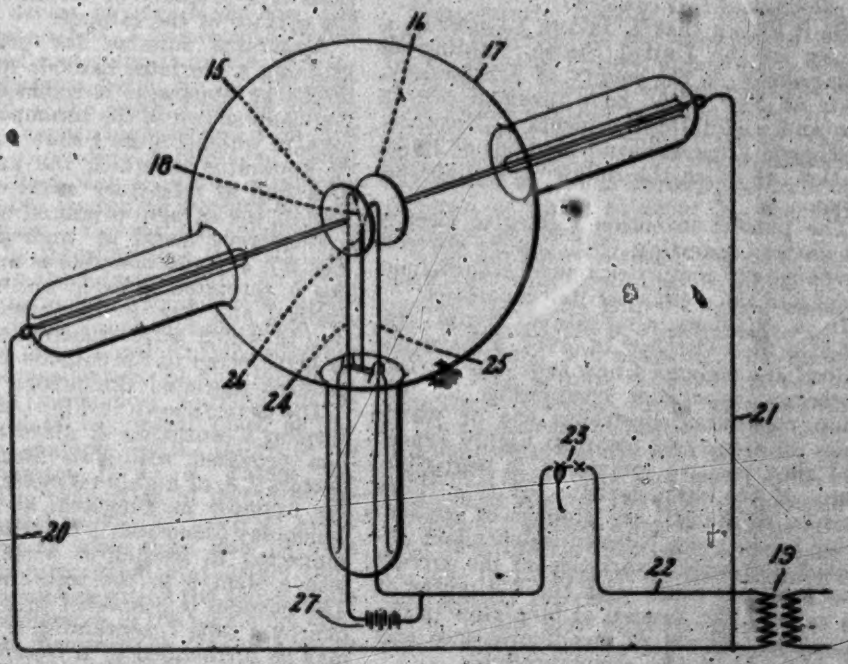
I. LANGMUIR.

ELECTRON DISCHARGE APPARATUS AND METHOD OF PREPARATION.

APPLICATION FILED JULY 15, 1914. RENEWED JUNE 25, 1917.

1,244,216. Patented Oct. 23, 1917.

Fig. 2.



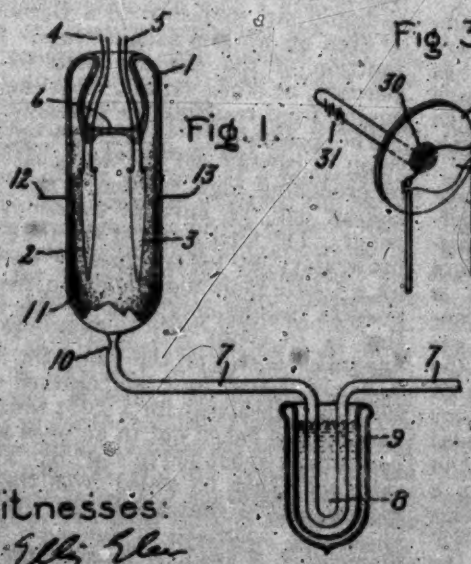
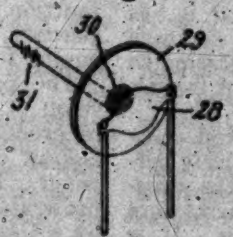


Fig. 1.

Fig. 3.



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Inventor:
Irving Langmuir,
by Albert G. Davis
His Attorney.

UNITED STATES PATENT OFFICE.

IRVING LANGMUIR, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

ELECTRON-DISCHARGE APPARATUS AND METHOD OF PREPARATION.

1,244,216. Specification of Letters Patent. Patented Oct. 23, 1917

Application filed July 15, 1914, Serial No. 851,085. Renewed June 25, 1917. Serial No. 176,988.

To all whom it may concern:

Be it known that I, IRVING LANGMUIR, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Electron-Discharge Apparatus and Methods of Preparation, of which the following is a specification.

The present invention relates to electrical devices operating with a pure electron discharge and comprises a novel cathode material and the method of its preparation.

In a previous application, Serial No. 795,610, filed October 16, 1913, I have described and claimed a new type of electrical discharge apparatus comprising an envelop containing electrodes one of which emits electrons and being so highly evacuated that positive ionization is negligible. Some of the characteristics of this "pure electron discharge" are absence of conductivity in the space between independent unheated electrodes, a variation of the current over a certain range with the 3/2 power of the voltage, the absence of blue glow in the space, the absence of gas fluorescence and the lack of cathodic disintegration.

Various refractory materials, platinum, carbon, tungsten and molybdenum, have been used as cathode materials and it has been found that the emissivity of electrons of these various materials while differing to some degree is of the same order of magnitude.

I have discovered that the electron emissivity of pure thorium is of an entirely different order of magnitude than the emissivity of refractory materials heretofore used in electron discharge devices. It is not necessary that the electrode should consist entirely of thorium. When, for example, a thorium compound, such as the oxid, has been added during the process of production to one of the highly refractory metals, for example, tungsten, and the metal subjected to a preliminary heat treatment in a high vacuum, the electron emission in a high vacuum is enormously increased. This increased emissivity is not due to the presence of thorium oxid in the manner of the Wehnelt cathode for various reasons hereinafter explained, but according to all indications is a property of metallic thorium on the surface of the cathode.

Apparatus suitable for preparing and utilizing a thoriated cathode in an electron discharge apparatus is somewhat diagrammatically shown in the accompanying drawings, in which Figure 1 shows a simple type of apparatus in which the anode consists of a film of refractory metal on the inside wall of the envelop produced by vaporizing a refractory metal at high temperature; Fig. 2 is a device operable as a rectifier having a thoriated cathode and plate-shaped anodes; and Fig. 3 illustrates a modification in which active thorium material may be transferred to the cathode from an independent thoriated conductor.

The device shown in Fig. 1 comprising an envelop 1 consisting of glass, quartz or the like provided with two filamentary conductors 2, 3, of highly refractory metal, such for example as tungsten, at least one of which, say filament 2, is thoriated. They are connected to leading-in wires 4, 5, sealed into a stem 6 in the well-known manner. The envelop is connected to a vacuum system by a tube 7, containing a trap 8 which may be surrounded by a freezing bath, such as liquid air, contained in a Dewar flask 9 or even an ice and salt mixture. It is the function of the freezing bath to prevent mercury, or other vapors, from the vacuum pumps from reaching the envelop 1.

The preliminary evacuation of the envelop is carried out by the usual methods of producing high vacuum, which includes baking out the envelop to remove water vapor. The final stage of the evacuation is preferably but not necessarily carried out by a Gaede molecular pump to the highest possible vacuum obtainable by this means,—that is, to about .001 micron. While the apparatus is still on the pump the filaments 2, 3, are heated to a temperature of about 2900° K. (absolute) for a short time and the envelop 1 is baked out in an oven at a temperature of about 360 to 450° K. The apparatus may then be sealed from the vacuum system at the contraction 10. It is then preferably immersed in liquid air and both filaments 2, 3 aged by heating for about ½ hour to a temperature of 2400 to 2500° K. One of the filaments, for example, filament

3, is then incandesced by a passage of current to a temperature of about 3000° K. which causes rapid vaporization of the metal, thereby producing a gas-free conducting deposit or coating 11 which has been shown on the inner surface of the envelop. Conductors 12, 13 sealed into the envelop make contact with this coating and enable it to be used as an anode for an electrical discharge. A device having a gas-free film anode and the method of its preparation has been described and claimed by me in a co-pending application, Serial No. 843,569, filed June 6, 1914. The method of producing high vacua by vaporizing tungsten is claimed by me in a co-pending application, Serial No. 838,768, filed May 15, 1914. Pressures much below .001 micron of mercury may be attained thereby. The cathode conductor 2 is prepared by introducing a thorium compound, such as the nitrate of thorium to the oxid of the refractory metal before reduction, or by adding either thorium nitrate or thoria to the metal powder after reduction but before consolidation of the metal by sintering and mechanical working to the solid metal state has taken place as described, for example, with reference to thoriated tungsten in U. S. Patent No. 1,082,933. The proportion of thoria in the unsintered metal usually varies from about ½ to 10% but in some cases may be even greater. The proportion of thorium compound in the cathode within the above limits makes little difference in the maximum electron emission that may be obtained under the best conditions but with a greater proportion of thorium compound the desired active condition of the filament may be reached and maintained with greater ease than with a lesser amount.

The thoriated cathode 2 is now heated to about 2900° K. for about one minute. The treatment of the filament at a temperature of 2900° has no marked effect on the subsequent electron emission of the cathode when at lower temperature but appears to be desirable for purifying the surface of the cathode. The cathode is then incandesced within the range of about 2000° to 2400° K. and by this temperature treatment some change is produced in the cathode which enormously increases its electron-emitting property under the condition described. The greatest activity is obtained between about 2200° to 2300° K. and the treatment at this temperature is usually continued for about one minute, but even outside of this range a marked change is produced. Apparently a concentration of metallic thorium or of some other oxidizable thorium material takes place on the surface of the filament. The filament 2 may now be used as a cathode at a temperature below this forming temperature.

With a filament thus prepared I have obtained at a temperature of about 1300° to 1380° K. substantially the same electron emission per sq. cm. as with a pure tungsten filament at about 2000° K., that is, about three milliamperes per sq. cm. Preferably a thoriated cathode is operated around 1700° to 1800° K., at which temperatures its life is indefinitely long.

Subsequently heating the filament to a higher temperature, for example, to 2800° K., causes some change, apparently a distillation of the film of thorium from the surface, as the electron emitting power of the cathode falls to the same order of magnitude as pure metal. When the cathode after being thus heated is re-subjected to a temperature of 2200° to 2300° K., the active condition is restored.

A similar heat treatment of pure tungsten has no effect on its electron emissivity at incandescence. The active thorium material may be transferred by distillation to an adjacent surface. For example, if the filament 3 consisting of pure tungsten has not been completely destroyed during the preparation of the apparatus, the heating of the cathode to a temperature above 2300° after the preparation of the surface film results in the distillation of some of the thorium material to conductor 3 so that when the conductor 3 is used as a cathode with respect to the anode 11, it is found that its electron emission has been greatly increased.

One of the most striking proofs that the active surface film is not due to the effect of the thoria as in the Wehnelt cathode is furnished by the effect of a minute trace of oxygen on the behavior of the cathode. If in some manner a trace of oxygen is admitted, the electron emission immediately falls as low or even lower than the low value observed when a cathode of pure tungsten is slightly oxidized. In other words, the electron emission becomes very much lower than that of the unoxidized metal. When subsequent to oxidation a trace of hydrocarbon vapor is admitted, the electron emission suddenly rises as though reduction were taking place. If the carbon is in excess, the electron emissivity immediately drops to a low value as though a carbid were formed with the excess of carbon. In an application Serial No. 58,377 filed by me on October 28, 1915, I have more fully described and also claimed a thoriated cathode device containing reducing material.

Cathodes containing only a small amount of thorium compound are deleteriously affected by disintegration of the surface produced by positive ion bombardment and in this respect may be extremely sensitive. In this case it is necessary when using voltages high enough to cause ionization of residual gases to carry the vacuum far beyond the

point at which a disruptive discharge no longer takes place, which ordinarily is about $\frac{1}{10}$ of a micron of mercury pressure. The Wehnelt or oxid cathode apparently depends on positive ionization for its activity. At any rate its emissivity is increased by an increase in positive ionization. When large amounts of thorium are present in my improved cathode, it is not so sensitive to positive ion bombardment and it is possible to obtain to a large extent the advantages of a thoriated cathode even in the presence of pressures of gas up to atmospheric pressure.

Another proof that the high electron emission is due to a skin of thorium is the fact that metallic thorium itself, particularly when free from surface oxidation, exhibits a very high electron emissivity for a given temperature as compared with tungsten. Difficulties are encountered with the use of metallic thorium as cathode material due to its relatively low melting point and its susceptibility to oxidation.

At 2000° to 2300° K., the active thorium is slowly diffusing to the surface from the interior of the metal. As the temperature is raised a point is reached where the distillation of thorium from the surface exceeds the rate at which the metal diffuses to the surfaces. It is possible, however, to operate a refractory thoriated cathode at a temperature between 2000° and 2300° K. for a long time without destroying its high electron emission, but operation at a higher temperature is not advisable. A sufficiently great electron emission can be secured through the indicated temperature range with an accompanying saving of energy necessary for heating the cathode.

The apparatus shown in Fig. 2 does not differ essentially from the apparatus shown in Fig. 1, plate-shaped anodes 15, 16 consisting of a highly refractory metal such as tungsten being used instead of the film anode of vaporized metal used in the apparatus shown in Fig. 1. The envelop 17 is baked out and evacuated as already described in connection with Fig. 1. The ionizable gas should be removed from the anodes during the final stages of the exhaust after the pressure has been reduced below about $\frac{1}{10}$ of a micron of mercury by subjecting the anodes to an electron discharge from the cathode 18 whereby ionizable gas is evolved, as disclosed in my co-pending application, Serial No. 795,610 of October 16, 1913. This gas should be removed as fast as liberated and the discharge voltage progressively increased, care being taken not to materially exceed the voltage at which blue glow takes place so as to avoid injury to the cathode. The final stage of the evacuation is produced by vaporizing a tungsten conductor in a side chamber (not shown in the drawing), thereby producing the very high vacuum necessary for the operation of the thoriated cathode. The anodes 15, 16 may be both connected to one terminal of a secondary of the transformer 19, by conductors 20, 21, the cathode being connected to the other terminal by conductor 22, including a load circuit 23. The cathode 18 has been merely indicated by dotted lines as being a V-shaped filament supported by terminal wires 24, 25, and maintained taut at its bight by a spring 26, but it is to be understood that it may have any convenient form. Thorium compound, for example, the oxid, is introduced during the process of manufacture as already described. The apparatus here shown is suitable for the rectification of alternating current when the cathode is maintained at incandescence by a battery 27, preferably at a temperature of 1700 to 1800° K.

It is not absolutely necessary that the thorium should be introduced into the body of the metal during the process of manufacture. As shown in Fig. 3 a cathode 28 located opposite an anode 29 is provided with a film of active thorium material vaporized from the coiled filamentary cathode 30 heated by a battery 31. The cathode 30 may consist either of a thoriated cathode prepared as already described, or of metallic thorium. The inclosing envelop has not been shown, but it is to be understood that these parts are to be operated in the high vacuum already indicated as being desirable. When the coil 30 consists of thoriated wire it is first rendered active by heat treatment at a temperature of 2200° to 2300° K., as already described, and is then heated to a temperature of about 2900° K. to distil off active material, some of which is condensed on the cathode 28. When the coil 30 consists of metallic thorium, it should be heated to a temperature near its melting point to distil some of the thorium over on to the surface of the cathode 28.

As positive ionization is very much decreased at low voltages, it is permissible to have present an inert gas at a pressure of say .01 micron when the voltage impressed between the cathode and anode does not arise above the ionizing potential of the gas. Advantage can be taken of this fact to use an electron discharge device containing a thoriated cathode as a voltage sensitive cut-out device. Below the voltage at which disintegration of the surface begins, a device such as shown in Fig. 1 may be used to pass a current of about $\frac{1}{10}$ of an ampere per sq. cm. when the cathode is at a temperature of about 1700° to 1800° K. When the voltage rises above the critical value, the current immediately drops to a very small value, thus practically interrupting the circuit. The cathode may be restored when the voltage

has fallen by again heating it to about 2300° to 2350° K.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. In an electrical discharge device, an electrode comprising in part at least oxidizable thorium material, said electrode having at a temperature of about 1300 to 1380° absolute an electron emission substantially equal to that of tungsten at about 2000° absolute.

2. In an electrical discharge device, an electrode comprising in part at least oxidizable thorium and having when at incandescence in a vacuum so highly attenuated that positive ionization is substantially absent, an electron emission materially greater per unit of surface than tungsten at the same temperature.

3. A cathode for electron-discharge apparatus consisting largely of a highly refractory metal and a surface layer of material having an electron emissivity at a given temperature materially greater per unit surface than said refractory metal independently of and in the absence of positive ionization.

4. In a device operating by pure electron discharge independent of positive ionization, a conductor comprising a refractory metal and a surface film of thorium material vaporizable at a temperature above about 2300° K. and having a greater electron emission when at incandescence in a non-striking vacuum than said refractory metal.

5. In an electrical discharge device, an electrode comprising metallic tungsten and a surface film of thorium material vaporizable at a temperature above about 2300° K. removable from said surface by positive ionization and having an electron emission per unit surface many times greater than pure tungsten at the same temperature.

6. In an electrical discharge device, an electrode comprising metallic tungsten and thoria said electrode having been subjected to a temperature of about 2200 to 2350° K. and having an electron emission a thousand times as great per unit of surface as tungsten in a vacuum too high to permit of positive ionization.

7. In an electrical discharge device, a cathode comprising metallic tungsten and thoria, said electrode having received a heat treatment at about 2000 to 2350° K. and having an electron emission when at incandescence at a given temperature of a higher order of magnitude than pure tungsten at the same temperature.

8. The process of preparing an electrode comprising a refractory metal and thoria for use in a pure electron discharge apparatus which consists in heating said electrode to a temperature adjacent the melting point of said refractory metal and then heating to a temperature of about 2200 to 2300° absolute.

9. The process which consists in heating a conductor comprising tungsten and thoria to a temperature of about 2800 to 2900° absolute and then lowering the temperature to about 2200 to 2300° absolute holding said temperature for a short interval and finally operating said conductor as cathode in a non-striking vacuum at a temperature below 2000° absolute.

10. A cathode for electron discharge apparatus consisting largely of tungsten and containing thorium, said cathode having an electron emissivity, independently of and in the absence of positive ionization, at a given temperature materially greater per unit surface than tungsten at the same temperature.

11. In an incandescent cathode device, an electrode comprising a highly refractory metal and containing oxidizable thorium material, said electrode having an electron emissivity per unit surface many times greater than said refractory metal alone at the same temperature, the electron emissivity of said cathode being lowered by the presence of oxygen and by positive ionization.

In witness whereof, I have hereunto set my hand this 14th day of July, 1914.

IRVING LANGMUIR

Witnesses:
WILLIAM C. WHITE,
HELEN ORFORD.

16

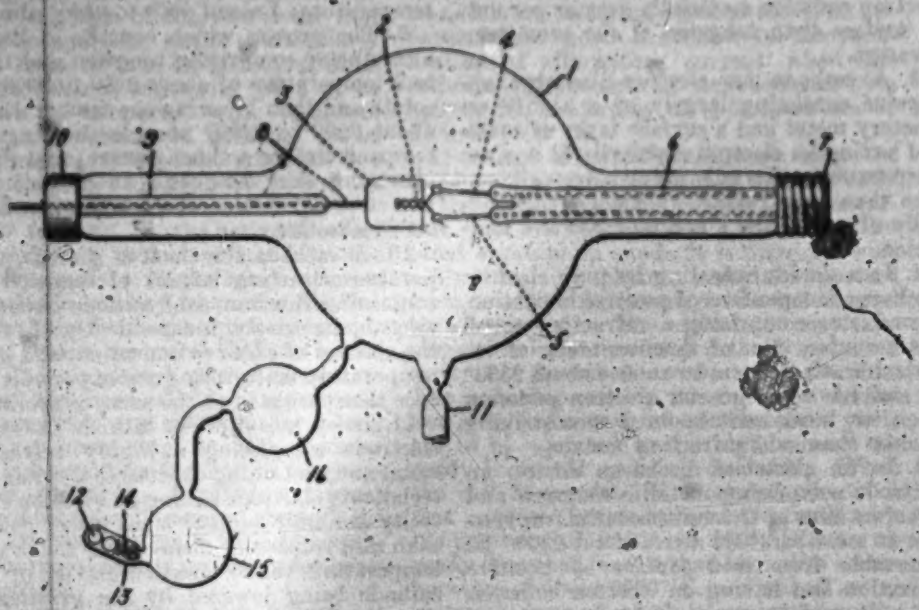
PLAINTIFF'S EXHIBIT No. 3.

I. LANGMUIR.

ELECTRON DISCHARGE APPARATUS AND METHOD OF OPERA...G THE SAME.

APPLICATION FILED OCT. 28, 1916.

1,244,217. Patented Oct. 23, 1917



Inventor:
Irving Langmuir,
by Albert G. Davis,
His Attorney.

UNITED STATES PATENT OFFICE.

IRVING LANGMUIR, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

ELECTRON-DISCHARGE APPARATUS AND METHOD OF OPERATING THE SAME.

1,244,217. Specification of Letters Patent. Patented Oct. 23, 1917.

Application filed October 23, 1913. Serial No. 796,377.

To all whom it may concern:

Be it known that I, IRVING LANGMUIR, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Electron-Discharge Apparatus and Methods of Operating the Same, of which the following is a specification.

The present invention relates to electrical devices having an electrode consisting at least in part of thorium and having at a given temperature an electron emission per unit surface materially greater than the emission of a refractory metal such as tungsten at the same temperature independently of and in the absence of positive ionization. These devices are described and claimed in a copending application, Serial No. 851,095, of July 19, 1914, renewed on June 25, 1917, as application Serial No. 176,926, to which the present application is closely related.

In the preparation of these devices great care must be exercised to remove the last traces of oxygenous gases, particularly water vapor, and precautions must be observed not to evolve water vapor from the bulb walls during the operation of the device.

In accordance with my present invention, I have improved the above described device and also rendered easier the preparation of the same by providing in the envelop a quantity of a vaporizable reagent of low vapor pressure capable of preventing the oxidation of thorium. I prefer to use for this purpose an alkali metal, such for example, as potassium.

The accompanying drawing illustrates one particular form of apparatus to which my invention is applicable, namely, an incandescent cathode discharge device provided with means for introducing the desired reagent.

The device shown in the drawing which may be used for rectifying alternating current, comprises an envelop 1 consisting of a glass not chemically attacked by alkali metal provided with a cathode 2 consisting for example of thoriated tungsten, and a cylindrical or cup-shaped anode 3, also consisting of a highly refractory metal, such for example, as tungsten. A heating current may be conveyed to the cathode by leading-in conductors 4, 5, sealed into a stem 6 in the usual manner and connected to a threaded socket 7 similar to an incandescent lamp socket. The anode stem 8 is also sealed into a glass stem 9 and attached to an external metal cap 10.

The cathode 2 is prepared by adding a thoria compound, such as nitrate of thorium to the oxid of tungsten before reduction of the metal, or by adding either thorium nitrate or thoria to the metal powder after reduction, but before consolidation of the metal powder by sintering and mechanical working to the solid state as described, for example by reference to thoriated tungsten in U. S. Patent #1,082,933. The proportion of thoria in the unsintered metal usually varies from ½ to 10% but in some cases may be even greater. The proportion of thorium compound within the above limits makes little difference in the maximum electron emission that may be obtained under the best conditions but the favorable conditions will be more easily attained with a greater than with a lesser amount.

The preliminary evacuation of the envelop is carried out by the usual methods of producing a non-striking high vacuum, which includes baking out the envelop to remove water vapor. The final stage of the evacuation is preferably but not necessarily carried out by a Gaede molecular pump to the highest possible vacuum obtainable by this means, that is, to about .001 micron. While the apparatus is still on the pump the cathode 2 is heated to a temperature of about 2900° K. (2727° C.) for a short time and the envelop 1 is baked out in an oven at a temperature of about 360 to 450° C.

The substance to be distilled into the envelop, for example, potassium, is inclosed at 12 in a small side chamber 13, a small quantity of glass particles, or glass wool, 14 being preferably placed in front of the reducing material. As already indicated all glasses (including the glass wool) used in the apparatus should be unattacked by alkali metal. When the envelop is baked out care should be exercised not to heat the chamber 13 to too high a temperature. The potassium or other material, is transferred by melting into a communicating chamber 15, after which the chamber 13 may be sealed off. Thereupon, the material is distilled into a second communicating chamber 16 and

finally a very small amount is introduced into the main envelop 1, both the chambers 15, 16 being successively sealed off. The redistillation of the reducing material serves to purify it. Although alkali metals have been indicated as preferable for the purposes of my invention, other reducing materials may be used, for example, hydrocarbon compounds. The bulb is finally sealed from the vacuum system at the contraction 11.

The thoriated cathode 2 is now heated to about 2900° K. for about one minute. The treatment of the filament at this temperature appears to be desirable for purifying the surface of the cathode. The cathode is then incandesced within the range of about 2000° to 2400° K. and by this temperature treatment some change is produced in the cathode which enormously increases its electron-emitting property under the condition described. The greatest activity is obtained between about 2200° to 2300° K. and the treatment at this temperature is usually continued for about one minute. Apparently a concentration of metallic thorium or of some other oxidizable thorium material takes place on the surface of the filament. The filament 2 may now be used as a cathode at or below this forming temperature.

The presence of the reducing agent in the main receptacle maintains the thorium reduced in spite of traces of water vapor which may be liberated from the glass. In any event the high electron emissivity of the thoriated cathode is more easily secured and maintained in the presence of the reducing agent than without it.

With a filament thus prepared I have obtained at a temperature of about 1300° to 1380° K. substantially the same electron emission per sq. cm. as with a pure tungsten filament at about 2000° K., that is, about three milliamperes per sq. cm. A thoriated cathode may be operated around 1700° to 1800° K., at which temperatures its life is long, and thermionic current may be obtained many thousands of times greater than obtainable with pure tungsten at the same temperature.

Subsequently heating the filament to a higher temperature, for example, to 2800° K. causes some change, apparently a distillation of the film of thorium from the surface, as the electron emitting power of the cathode falls to the same order of magnitude as pure tungsten. When the cathode after being thus heated is re-subjected to a temperature of 2200° to 2300° K. the active condition is restored.

The vapor pressure of potassium, sodium or other alkaline metal at room temperature is so low that objectionable positive ionization of its own vapor during the operation of the pure electron device is negligible and the vapor pressure of the oxidation products of the alkaline metal have no perceptible vapor pressure. For this reason, the alkali metals are to be preferred to carbonaceous compounds as reducing agents in the present device.

The vapor of alkaline metals does not produce an increased emission of a pure tungsten filament thereby furnishing proof that the beneficial effect of the alkaline metal is exerted upon thoria content of the filament and is not due to some ionization phenomena.

Under carefully controlled conditions the benefit of the increased electron emission of a thorium-containing cathode may be secured in a device filled with an inert gas, such, for example, as argon or other monatomic gases, at pressures ranging from a few millimeters of mercury pressure upward, in the presence of potassium or equivalent material for preventing the oxidation of thorium. Care must be exercised to have the cathode at a high enough temperature with reference to the current transmitted so that the vicinity of the cathode is surrounded by free electrons. In other words, the electron emission should be greater than necessary to convey the current thereby preventing a removal of the active thorium material on the surface of the cathode by a bombardment of positive ions.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. An electrical discharge device comprising electrodes, one of which contains thorium, an inclosing envelop the space within which is evacuated to a pressure so low that positive ionization is substantially absent, and a quantity of a vaporizable reagent capable of preventing the oxidation of thorium in communication with the space within said envelop.

2. In an electrical discharge device, an inclosing envelop, a quantity of alkali metal within said envelop, and electrodes therein, one of which comprises in part at least, oxidizable thorium material, said electrodes having at a temperature of about 1300 to 1380° absolute an electron emission substantially equal to that of tungsten at about 2000° absolute.

3. In an electrical discharge device, an inclosing envelop, a quantity of potassium within said envelop, and electrodes therein, one of which consists largely of tungsten and containing thorium, said electrode having an electron emissivity at a given temperature materially greater per unit surface than tungsten at the same temperature.

4. An electrical discharge device comprising electrodes, one of which consists of metallic tungsten and a thorium material in an oxidizable state, an inclosing envelop, and a quantity of a vaporizable reagent within said envelop capable of preventing

the oxidation of thorium at an elevated temperature.

5. The process of improving the operation of an electron discharge apparatus containing an electrode operating at incandescence comprising a highly refractory metal and a thorium material which consists in bringing into contact with said electrode the vapor of a reagent preventing the oxidation of thorium at an elevated temperature.

6. The process of improving the operation of an electron discharge apparatus containing an electrode of tungsten and thorium operating at incandescence in a non-striking vacuum, which consists in bringing into contact with said electrode the vapor of an alkali metal at a pressure too low to cause appreciable positive ionization phenomena.

7. An electrical device comprising the combination of a sealed evacuated envelop, a refractory cathode, means for heating said cathode to incandescence, a cooperating anode and a quantity of potassium within said envelop.

8. An electrical device comprising the combination of an evacuated envelop, a cathode, an anode and a quantity of alkali metal inclosed within said envelop, and means for heating said cathode to incandescence.

In witness whereof, I have hereunto set my hand this 27th day of October, 1915.

IRVING LANGMUIR.

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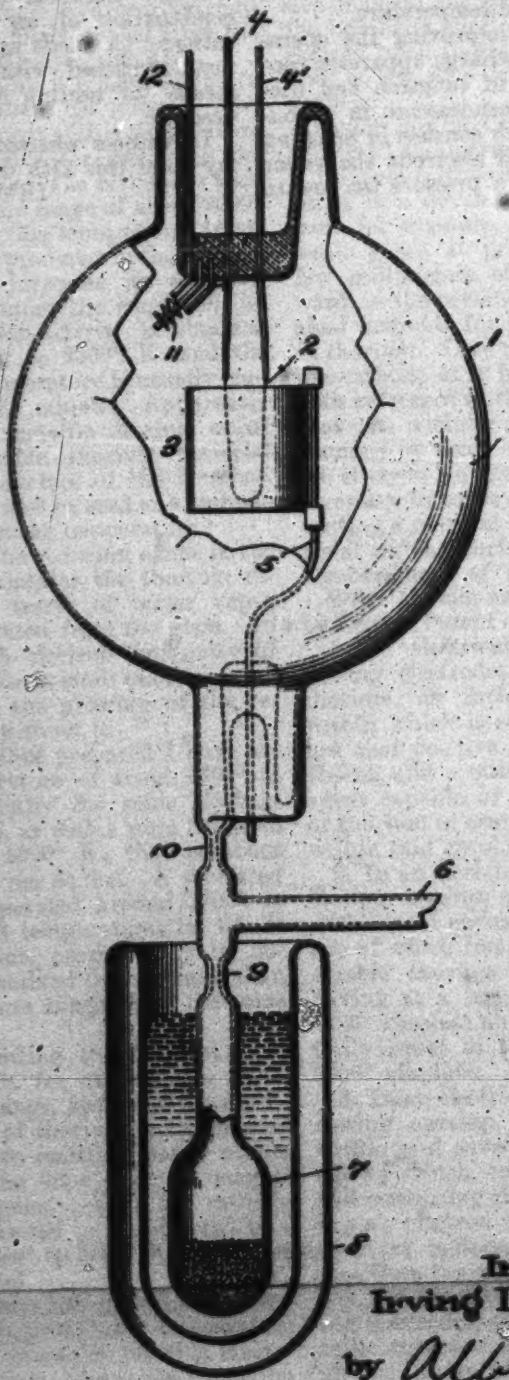
PLAINTIFF'S EXHIBIT No. 4.

March 10. 1925. 1,529,597

I. LANGMUIR

ELECTRON EMITTING DEVICE AND METHOD OF PREPARATION

Filed Aug. 11, 1921



Inventor:
Irving Langmuir
by Albert G. Davis
His Attorney

Patented Mar. 10, 1925. 1,529,597

UNITED STATES PATENT OFFICE.

IRVING LANGMUIR, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

ELECTRON-EMITTING DEVICE AND METHOD OF PREPARATION.

Application filed August 11, 1921. Serial No. 491,634.

To all whom it may concern:

Be it known that I, IRVING LANGMUIR, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Electron-Emitting Devices and Methods of Preparation, of which the following is a specification.

This invention comprises an improvement in the electron emitting cathodes of the type described in my prior U. S. Patents Nos. 1,244,216 and 1,244,217.

In these patents I have described the preparation and advantages of a vacuum tube containing a cathode adapted to be operated at incandescence and containing distributed throughout its mass thorium (or a compound of thorium) as a constituent. This type of electrode consists of a refractory conducting material, such for example as tungsten, with an addition of a material capable of increasing the electron emissivity of the cathode, such for example as thoria, the latter being subjected to modifications during the preparation of the cathode in the electron discharge device so that the active material in a finished device according to all indications, consists of metallic thorium or at least of a lower oxide of thorium than thoria (ThO_2). The cathode prepared according to the methods set forth in my first Patent 1,244,216 which is commonly known as a "thoriated cathode", is very sensitive to traces of oxidizing gas in the bulb, as for example, small traces of water vapor which may be given off from the walls of the bulb during the normal operation of the device. In order to prevent loss of activity of the cathode, I have described in my second Patent No. 1,244,217, the beneficial results obtained by the admission to the bulb of a small amount of alkali metal, such as potassium or sodium, or of a hydrocarbon compound.

My present invention in one of its aspects is based on the discovery that carbon in a cathode of the thoriated type, when present in a definitely limited amount, will prevent not only reoxidation of active thorium material but what is more important, will act beneficially to reduce thoria to the active state. Although the thoriated cathodes described in my prior patents can be used with satisfactory results, I have found that a further improvement in regularity and stability can be effected by using carbon as hereinafter described, not only as in accordance with my prior patent in restricted quantities, as an oxidation preventing agent, but, as hereinafter described, as an ingredient of a thoriated cathode.

In accordance with another feature of my invention my improved cathode is used in conjunction with a non-carbonaceous reducing agent which is provided in the bulb, as for example, a highly oxidizable metal.

A thoriated cathode may be deleteriously affected by positive ion bombardment, that is, when voltages materially higher than the ionization voltages are impressed between a thoriated cathode and a positive electrode in the presence of ionizable gas, then the beneficial effect of the thorium may be largely or entirely destroyed by positive ion bombardment. Although the alkali metals are entirely satisfactory as agents to remove deleterious gases when the operating temperature of the bulb is only moderately above room temperature, as in the case of radio receiving tubes, these alkali metals have a sufficiently high vapor pressure at the operating temperature of power devices in which cathodes of the thoriated type are used to become ionized at higher voltages and to cause removal of the active film of thorium from the cathode by bombardment. I have found that it is advantageous in many cases to provide a device containing a cathode of the thoriated type with a material having an affinity for gases, such as magnesium, for example, which at the operating temperature of the device has substantially no vapor pressure. My invention will be pointed out with greater particularity in the accompanying claims and described fully in conjunction with the accompanying drawing which shows somewhat diagrammatically. An apparatus used for carrying out the preparation of an incandescent cathode rectifier.

The rectifier shown in the figure is illustrative of one of the various forms of incandescent cathode devices. It consists of a bulb 1 containing a filamentary cathode 2 into which thoria has been introduced as described in my above mentioned prior patents, and an anode 3, consisting of tungsten,

molybdenum or other suitable material. These electrodes are respectively connected to lead wires 4, 4' and 5 sealed into the walls of the bulb. The bulb is connected to the usual pumping system by means of a tubulature 6. The bulb also communicates with an elongated tube 7 adapted to be surrounded by a freezing mixture contained within a double-walled receptacle 8.

In carrying out my invention, the bulb 1 is first baked out as usual to remove water vapor and is then exhausted. Within the tube 7 is placed a substance adapted to give a low pressure of carbonaceous vapor, as for example, anthracene ($C_{14}H_{10}$) or naphthalene ($C_{10}H_8$).

When the vapor pressure of the substance employed is relatively high, I prefer to reduce the pressure of the hydrocarbon vapor in the bulb 1 by surrounding the tube with a freezing agent contained in the receptacle 8. When employing naphthalene, which has a moderately high vapor pressure, I prefer to reduce the temperature of the containing tube 7 to about −20 to −30° C. to reduce the vapor pressure to about 0.1 to 0.01 microns. The bulb 1 which communicates with the side tube 7, therefore, is filled with hydrocarbon vapor at approximately this pressure. The quantity of hydrocarbon may be controlled by one or more constrictions, such as 9, 10 which may regulate the pressure with or without a freezing agent.

The filament 2, which preferably consists of metallic tungsten, containing about ½% thoria, is heated to a temperature of about 2300° K. (2000° C.) for a few minutes, in contact with the hydrocarbon vapor. At this temperature the incandescent filament decomposes the hydrocarbon vapor which comes in contact with the incandescent surface of the tungsten and causes the chemical combination with the tungsten of the carbon set free from the naphthalene vapor, with the formation of tungsten carbide (W_2C). The heating is continued for a length of time sufficient to give an increase in resistance of about 15 to 25% of the tungsten filament when cold, or at room temperature. This change in resistance corresponds to the presence of about two-thirds per cent of carbon by weight in the filament.

The carbon content most beneficial will vary with the conditions. In the case of a thoriated tungsten cathode all of the metallic tungsten will be converted to brittle tungsten carbide (W_2C) with a carbon content as high as 3%. Ordinarily a carbon content as high as about 1% is as high as permissible without unduly weakening the cathode. Although the presence of even minute amounts of carbon is highly undesirable in an incandescent lamp, a commercially long life can be obtained in a thoriated cathode containing carbon, as the cathode need be operated only at a relatively low temperature, say at about the operating temperature of an ordinary carbon lamp, the electron emissivity of a thoriated cathode being so much greater than that of an ordinary pure tungsten cathode. The hydrocarbon vapor is removed from contact with the filament either by sealing off the tube 7 at the contraction 9 or cooling the side tube 7 by means of liquid air in the receptacle 8 to a temperature so low that the vapor pressure of the naphthalene is negligible, thereby removing the naphthalene vapor from the bulb 1.

In some cases carbon to a desired proportion may be combined with the cathode prior to the introduction of the cathode into the bulb 1. For example, a thoriated filament may be prepared by squirting tungsten and thoria with a carbonaceous binder in amounts adapted to leave a suitable restricted proportion of carbon in the finished product.

As the next step in the preparation of the device, the anode 3 is deprived of gases by the usual method of electron bombardment; that is, by passing a discharge between the cathode at incandescence and the anode, the exhaust pump in the meantime being operated to remove the vapors and gases which are liberated. During this step some of the carbon is removed by oxidation and evaporation from the cathode but with an original carbon content of about ⅔ of one per cent, enough carbon remains subsequently to furnish a supply of active thorium material by reduction of the thoria.

After the cathode has been provided with a content of reducing agent a non-carbonaceous material capable of combining with water vapor and other deleterious gases may be introduced into the bulb. In some cases this non-carbonaceous reducing agent may consist of alkali metal, such as sodium or potassium. Cesium may be used to advantage in some cases, especially when some positive ionization is desired in the electron discharge device. Cesium can be conveniently provided by adding a mixture of cesium halide and metallic calcium as a paste to some part of the bulb, this method of introducing an alkali metal being claimed in an application, Serial No. 608,311, December 21, 1922, by Ernest E. Charlton.

When not desiring ionization of residual gases or vapors, I prefer to introduce for the reasons given above a reagent having a lower vapor pressure than the alkali metals, as for example, an alkaline earth metal such as magnesium, calcium, strontium, or the like. Conveniently this is done by providing within the bulb a small heating coil 11, consisting of tungsten or other suitable refractory material, and containing a small quantity of the metal to be vaporized. Pref-

erably I employ metallic magnesium. By heating the tungsten filament 11 with current conducted thru the lead wires 4, 12, some of the magnesium is volatilized and deposited on the inner surface of the bulb which is then sealed off at the contraction 10. As during the sealing off process there is a tendency to drive out a small quantity of gas from the heated glass, I prefer to heat up the filament 11 the second time, to volatilize a small additional quantity of magnesium, or the like, in order to combine chemically with what little gas may have gotten into the bulb during the sealing off operation.

The film of magnesium, or other equivalent metal, on the walls of the bulb will combine with any water vapor or oxygen which may be given off by the bulb, or any other parts of the device during its operation, and thereby prevent an oxidization of the active thorium material upon the surface of the cathode.

The tungsten cathode 2 is preferably heated for a very short time to about 2700° K. to volatilize any thorium oxide on its surface.

As a final step, the cathode is "activated", that is, brought into its highly active state by heating to a temperature of about 2200° K. for a few minutes. This results in the reduction of thoria by the carbon and causes the active thorium product to come to the surface of the cathode where it will be effective in increasing the electron emission during the operation of the device. The tube is then ready for operation.

As explained in my prior patents, a temperature materially higher than the activating temperature will result in the thorium being volatilized from the surface of the cathode. A fresh supply can be produced and caused to accumulate upon the surface by again activating or "forming" an electrode at about 2200° K. During normal operation, the cathode is heated to a temperature below about 2200° K. and as high as 2100° K. Under these conditions, the electron emission stays constant.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. In an electron discharge device, a cathode body of the thoriated type containing carbon in an amount insufficient to convert all of the metallic constituents of said cathode to a carbide but sufficient to render said cathode less sensitive to the deleterious effect of gases than a cathode body unprovided with carbon.

2. In an electron discharge device, a tungsten cathode of the thoriated type adapted to emit electrons when heated, containing carbon in an appreciable amount but less than three per cent by weight.

3. A cathode adapted to emit electrons at incandescence comprising tungsten, about three-quarters per cent thoria and about two-thirds per cent by weight of carbon.

4. The method of increasing the electron emissivity of an electrode of the thoriated type which consists in introducing carbon into said electrode in amounts insufficient to convert said metal to a carbide, sealing said electrode into a space substantially free from carbonaceous vapors and thereupon activating said electrode.

5. An electric discharge device comprising an evacuated envelope, electrodes therein one of which comprises a refractory metal, thorium oxide and carbon in an amount insufficient to convert said metal to a carbide, and a non-carbonaceous reagent capable of combining with deleterious gases in said envelope.

6. An electric discharge device comprising an envelope, an anode and a cathode of the thoriated type and a non-volatile material, which is capable of reducing thorium oxide, contained in said cathode in such small amounts that the durability of said cathode is not appreciably decreased.

7. An electric discharge device having a cathode comprising metallic tungsten, thorium oxide and carbon combined with said tungsten in an amount materially less than required to convert all the tungsten to a carbide.

8. The method of increasing the electron emissivity of a cathode of the thoriated type which consists in introducing carbon into said cathode in an amount less than about one per cent by weight, heating said cathode in a non-carbonizing and non-oxidizing environment to a temperature at which a carbide of said metal is formed, activating said electrode by heating to about 2200° K. and operating the same under such conditions that bombardment of the electrode by positive ions is inappreciable.

9. The method of increasing the electron emissivity of a cathode of the thoriated type which consists in introducing carbon into said electrode in an amount less than one per cent by weight, mounting said electrode in a bulb, evacuating the same, volatilizing magnesium in said bulb after evacuation, and activating said cathode by heating to an elevated temperature.

10. The method of preparing an electrode adapted to emit electrons at incandescence which consists in heating a conductor comprising refractory metal and thoria in a carbonaceous vapor to a temperature adapted to cause combination of carbon with said conductor, removing said vapor before the amount of carbon introduced into the filament exceeds one per cent, and heating said conductor in a non-oxidizing environment to a temperature at which electron emissivity is markedly increased.

11. The method of preparing an electrode adapted to emit electrons at incandescence which consists in heating to incandescence a conductor comprising tungsten and thoria in a carbonaceous vapor until a marked increase in cold resistance occurs by the introduction of carbon, discontinuing the heating before the tungsten has been largely converted to a carbide, and heating said conductor in the absence of said vapor in a reducing environment to produce a surface layer of thorium material having a markedly higher electron emissivity than the original conductor.

12. An electrical discharge device comprising a sealed envelope, electrodes therein which include a cathode of the thoriated type and a substance, having a marked chemical affinity for water vapor, deposited as a film of extensive surface upon the inside of said envelope, said substance having a materially lower vapor pressure than the alkali metals.

13. An electrical discharge device comprising a sealed envelope, electrodes therein one of which is of the thoriated type and a film of magnesium deposited on the inner surface of said envelope.

14. An electron discharge device containing a cathode of the thoriated type, said cathode being provided with a reducing agent sufficient in quantity to promote activation of said cathode, but restricted to an amount which will permit operation of said cathode at a temperature of effective electron emission with a commercially long life.

15. A cathode of the thoriated type for electric discharge devices containing less than about three per cent by weight of carbon.

16. An electric discharge device comprising an envelope, electrodes therein one of which comprises a refractory metal, a material reducible by carbon to a state of higher electron emissivity than said refractory metal at a given temperature, and a quantity of carbon in an amount insufficient to convert said metal completely to a carbide.

17. An electrical discharge device comprising a container, electrodes therein one of which contains less than three per cent of carbon combined therewith and a material capable of materially higher electron emissivity at a given temperature than the main constituent of said electrode, but being sensitive to positive ion bombardment, and a quantity of alkaline earth metal deposited in said container out of immediate contact with said electrodes.

18. An electrical discharge device comprising a container, electrodes therein one of which contains a material capable of materially higher electron emissivity at a given temperature than the main constituent of said electrode, but being sensitive to positive ion bombardment, and a quantity of alkaline earth metal deposited as a film on the inner surface of said container.

19. An electrical discharge device comprising a container, electrodes therein one of which contains a material capable of materially higher electron emissivity at a given temperature than the main constituent of said electrode, but being sensitive to positive ion bombardment, and a quantity of magnesium deposited as a film on the inner surface of said container out of immediate contact with said electrodes.

20. An electrical discharge device comprising a container, electrodes therein one of which consists largely of refractory metal and contains an oxide of a metal of high electron emissivity which when rendered active is sensitive to ion bombardment together with a reducing agent, and a quantity of alkaline earth metal, the latter being deposited as a film on the inner wall of said container.

21. An electrical discharge device comprising a glass bulb, electrodes therein one of which consists largely of refractory metal and contains a material capable when activated of substantially increasing the electron emission of the electrode with which it is associated but which is deteriorated by oxidation and positive bombardment, and a film of magnesium coating the inner surface of said bulb.

22. An electrical discharge device comprising a container, electrodes therein, one of which contains as a constituent a material capable of higher electron emission than the main constituent of said electrode but which is sensitive to positive ion bombardment, and to the chemical effect of water vapor under operating conditions, and a film of metal deposited from the vapor state in a vacuum on the wall of said container which metal has a high chemical affinity for water vapor and has a materially lower vapor pressure at the operating temperature of said device than the alkali metals.

23. The method of increasing the electron emissivity of a metallic electrode containing a compound capable upon reduction of materially increasing the electron emissivity of said electrode which consists in introducing carbon into said electrode in an amount insufficient to convert the metal constituting said electrode completely to a carbide and heating said electrode in a non-oxidizing and non-carbonizing environment to a temperature sufficiently high to activate said electrode, and thereupon operating said electrode under conditions which render the effect of positive ion bombardment of said electrode inappreciable.

24. An electrode material for an electrical discharge device consisting of a metal capable of stable operation at an elevated tem-

perature, a compound of a material capable in a reduced state of higher electron emission than said metal, and carbon in a quantity insufficient to deleteriously affect the strength of said material, but being capable of reducing a sufficient amount of said compound to enable said electrode to be more readily activated during use than would be the case in the absence of said carbon.

25. A cathode material for electrical discharge devices consisting largely of a metal capable of operation at an elevated temperature, a reducible compound of a material of high electron emissivity and less than about one per cent of carbon.

In witness whereof, I have hereunto set my hand this 8th day of August, 1921.

IRVING LANGMUIR.

PLAINTIFF'S EXHIBIT No. 5.
DeForest Type H Rectifier Tube.

PLAINTIFF'S EXHIBIT No. 6.
DeForest Type H Audion Tube.

PLAINTIFF'S EXHIBIT No. 7.
DeForest DV 5 Vacuum Tube.

PLAINTIFF'S EXHIBIT No. 8.
DeForest DV 5 Vacuum Tube.

PLAINTIFF'S EXHIBIT No. 8-A.

Data Sheet Accompanying DeForest DV 5 Vacuum Tube.

INSTRUCTIONS FOR USING

De Forest Audion Type DV-5

Filament battery voltage: 6 Volts.
Filament current: .25 Amperes.
Plate Battery Voltage for:
1. Audio Frequency Amplifier,
   (a) Transformer coupled: 90—112½ Volts.
   (b) Resistance coupled: 112½—180 Volts.
2. Radio Frequency Amplifier: 67½—135 Volts.
3. Detector in a regenerative circuit only: 12—22½ Volts.

Resistance of rheostat for operating one DV-5 tube only: 15 ohms.

Resistance of rheostat for operating two or more DV-5 tubes in parallel: 6 ohms.

When "B" battery voltages greater than 90 volts are used on audio frequency amplifiers, the following "C" battery values should be applied:

"C" Battery Voltage	"B" Battery Voltage
1½ Volts	112½ Volts
3 "	135 "
6 "	157½ "
7½ "	180 "

When using the DV-5 as a Regenerative Detector use a Grid Condenser of .00025 mfd capacity and a Grid Leak of from 5 to 10 megohms.

The DV-5 may be used in all positions, but with particular advantage:—

As a Radio Frequency Amplifier in non-oscillating R.F. circuits.

As a Detector in Regenerative Circuits using low "B" battery voltage.

As an Audio Frequency Amplifier in Resistance coupled A.F. circuits.

As an Audio Frequency Amplifier in Transformer coupled A.F. circuits where the transformers are especially designed to handle considerable amounts of power.

As an Amplifier in Reflexed positions of Reflex circuits.

CAUTION

Keep the light in this Audion as dim as possible for clear reception. Most sets contain a "volume control" by which the desired volume can be obtained at low filament voltages.

Keep this "volume control" set near "Maximum." Then regulate the filament control for best reception. This will insure maximum life from De Forest Audions.

Recharge the "A" battery when it becomes necessary to advance the rheostat.

The lowest filament voltage which can be used to give good reception is the proper voltage for operating De Forest DV-5 Audions.

The DV-5 is designed to utilize a high "B" battery voltage. Maintenance of this voltage is absolutely necessary for proper working of any set containing DV-5 Audions.

A set of "B" batteries should never be used after the voltage has fallen below 15% of their original or rated value. As soon as it becomes necessary to light the filament in DV-5 Audions brighter than usual to secure the desired volume, test the "B" batteries. CONTINUED USE OF RUN DOWN "B" BATTERIES WILL RUIN THE AUDIONS.

Never connect new "B" batteries to old or run down "B" batteries. Change the entire set when the "B" voltage gets low.

Never attempt to operate two types of De Forest Audions with the filaments in parallel and controlled from one rheostat. To do so will greatly shorten the life of all of the Audions so used.

IMPORTANT

Handle De Forest Audions carefully. The Audion is a precision instrument requiring great skill and accuracy in its manufacture. It must be handled with as much care as any delicate instrument. Never lay them down on a hard surface but first put down a pad of cloth or other soft material on which to lay them.

Never change connections in or to the set without first removing the Audions.

When taking De Forest Audions out of sockets, or putting them in, ease them into or out of the sockets.

Never change the tubes without first turning the rheostats to "off" position.

Observance of all these precautions will insure long life and continued satisfaction from De Forest DV-5 Audions.

The DV-5 should be mounted in a vertical position. The use of a cushioned support for sockets is strongly recommended.

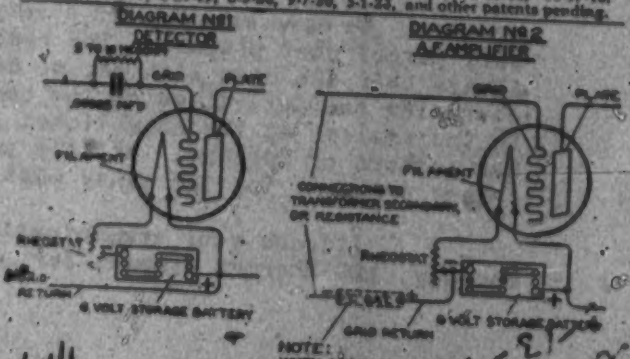
As a regenerative detector, the grid return should be connected to the positive filament terminal as in diagram 1.

As an Audio Frequency Amplifier the grid return should be connected to the negative "A" battery terminal with the rheostat placed as shown in diagram 2. When "B" battery voltages higher than 90 volts are used, the use of a "C" battery is necessary. The connections are shown in diagram 2.

As a Radio Frequency Amplifier, the grid return should be connected as described in the particular circuit being used.

WARNING: DO NOT INCREASE FILAMENT VOLTAGE ABOVE 5 VOLTS.

This tube is manufactured under U. S. Patents: 6-26-06, 11-13-06, 1-15-07, 10-8-07, 2-18-08, 4-7-08, 9-22-08, 12-20-10, 2-18-16, 10-17-16, 4-3-17, 7-29-19, 8-29-19, 8-3-20, 9-7-20, 5-1-23, and other patents pending.



DE FOREST RADIO COMPANY
Jersey City, N. J.

PLAINTIFF'S EXHIBIT No. 9.
Defendant's Circular.

DE FOREST RADIO COMPANY

TELEPHONE
WEBSTER 5720

CENTRAL AVENUE AT FRANKLIN STREET

JERSEY CITY, N.J.

BROADCAST TO ALL AMATEUR STATIONS
ANNOUNCING THE NEW DE FOREST "H" TYPE TRANSMITTING TUBE

It will be of interest to you to know that we have developed a new power tube which is designed to meet the requirements of the Amateur and Experimental stations in their work on short wave transmission.

The distinct features of this tube are that exceptional output wattage can be obtained without breakdown. Purposely no fixed output rating is being given this tube as its efficiency and function is dependent to a large extent upon power applied, circuit arrangement and wave length.

The tube will be known as the De Forest "H" type power tube. (see enclosed circular for approximate ratings.)

Grid, plate and filament leads are brought out at widely separated places of the tube, well insulated and giving every reasonable assurance against high frequency flashover.

The elements are rigid - Molybdenum is employed in both grid and plate - Each tube is carefully subjected to gas, oscillation, emission, insulation resistance and voltage tests.

The tube performs remarkably well on all wave lengths especially on those of from one meter to two hundred meters.

Those of the experimental and amateur stations which have been supplied with this new oscillator report exceptionally long distance results.

We have established a very low price on this tube, namely $18.00 net, parcel post prepaid. The reason for this price is that as has always been the case with us, we desire to continue as leaders in encouraging the activities of the amateur. The tube will be sold direct to the amateur at the established price. It cannot be bought through our jobbers or dealers. At this price it is necessary to ask that when orders are sent in, the money must accompany the order.

Address your communication to Department "T", De Forest Radio Company, 120 Sherman Avenue, Jersey City, N. J.

Yours very truly,
DE FOREST RADIO COMPANY

F. E. von Brandt

Manager, Tube Sales

WCvonB:BCH

DE FOREST
Receiving Tubes
with Low Loss Base
Sold by all Dealers

DeForest Audion	Filament Circuit			Plate Voltage		
	"A" Battery Voltage	Filament Terminal Voltage	Filament Current Amps.	R. F. Amplifier	Detector	A. F. Amplifier
DV3	6	5	.38 Max. .34 Min.	67½ to 135	11 to 22½	90 to 180
DV2	6	5	.38 Max. .34 Min.	67½ to 90	11 to 45	67½ to 90

Price $3.00

Long Distance Communication

Established by means of the new

DE FOREST "H" type Transmitting Tube

Price

Q.S.T.!

Short Wave Transmission a Success with

The New DeForest "H" Transmitting Tube

PLAINTIFF'S EXHIBIT No. 10.
Defendant's Leaflet.

Your Success on the Lower Waves

depends upon your selection of the proper transmitting tube.

Such a transmitting tube is now produced by the DeForest Radio Company, and will be sold under the designation of the

DeForest "H" Tube

Efficient performance is obtained by the "H" tube on wave lengths of from *1 Meter to 200 Meters;* in fact, on all wave lengths for which a circuit can be provided.

High frequency flash-over does not break down the tube as all leads are brought out at widely separated places.

High plate voltages may be used without fear of damage to any of the elements. Internal construction is rigid and the best of material is used. Both Grid and Plate are of Molybdenum.

The output ratings given below are approximate, because function and output efficiency depend largely upon the power applied, upon circuit arrangement and upon wave length.

No base is provided for this tube, in order to give it characteristics of a truly low loss oscillator.

Experiments conducted by the DeForest Laboratories indicate definitely that the new developments embodied in this "H" tube will now permit extremely long distance communication on the high frequencies.

TECHNICAL DATA

Plate Voltage	Grid Bias Volts	Filament Volts	Filament Amps.	Plate Current Milliamps.	Output R. F. Watts	Safe Plate Diss. Watts	Grid Leaks Hartley Circuit Ohms	Size Over-All
1000 to 3000	50 to 500**	10	2.35	40 to 110*	20 to 150**	170	5,000 to 100,000	6x3½"

*Values are with Tube Oscillating **Depends on circuit, grid leak and plate voltage

IN order that Amateurs and Experimenters may avail themselves of this high power transmitting tube at a reasonable cost, the DeForest Radio Company will supply these "H" tubes direct from the factory, (instead of through their regular sales channels) upon receipt of *Eighteen* ($18.00) *Dollars. Cash must accompany order.* Tubes will be mailed Parcel Post prepaid.

DeForest Radio Co.
120 SHERMAN AVENUE
JERSEY CITY, N. J.
DEPT. T

PLAINTIFF'S EXHIBIT No. 11.

Hogan Fig. 1, Diagram of Two Electrode Tube.

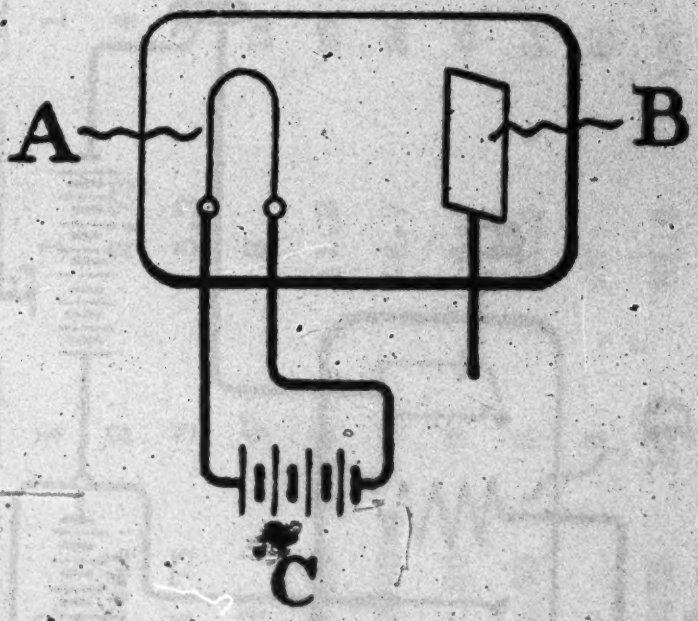


Fig. 1

PLAINTIFF'S EXHIBIT No. 12.

Hogan Fig. 2, Diagram of Three Electrode Tube.

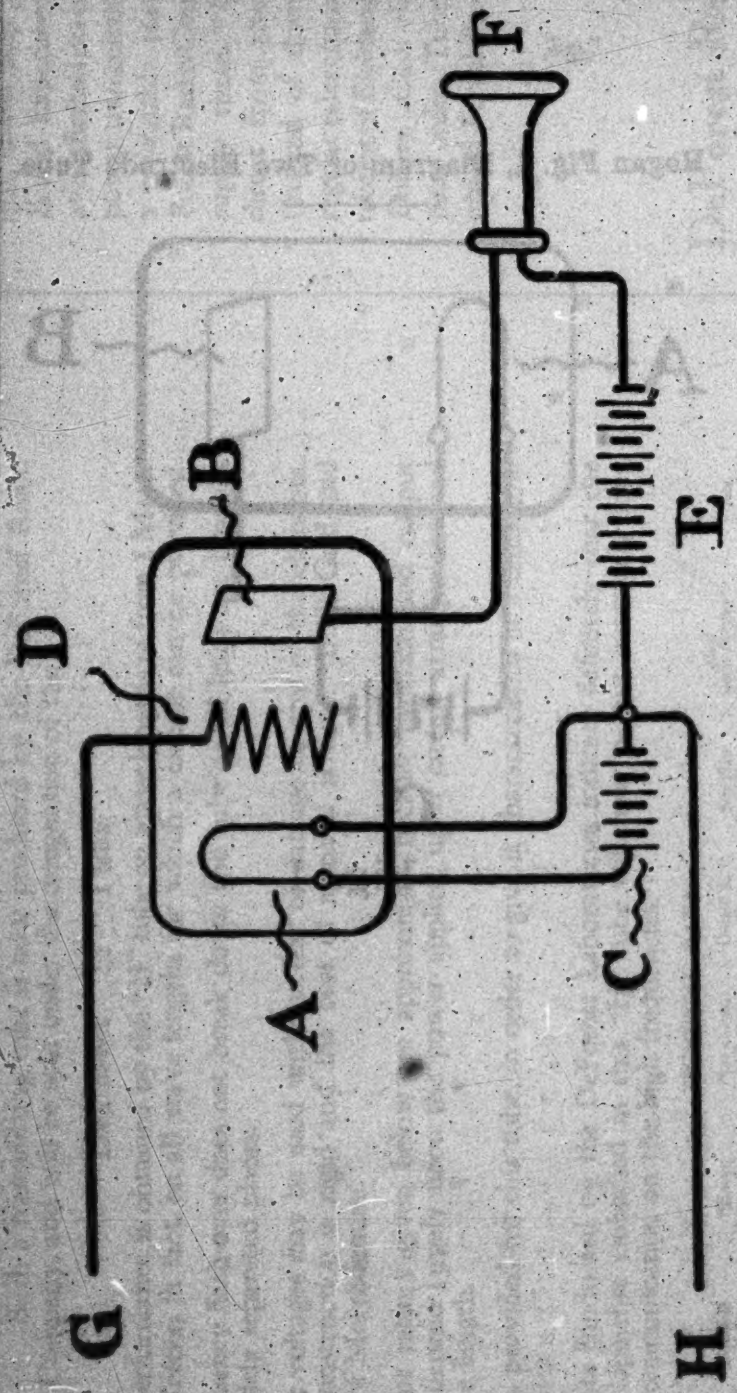


Fig. 2

Hogan Table I Showing Power of Numbers.

Table I

Number	Square Root	First Power	3/2 or 1½ Power	Second Power or Square	Third Power or Cube
1	1	1	1	1	1
2	1.41	2	2.73	4	8
3	1.73	3	5.2	9	27
4	2	4	8	16	64
5	2.24	5	11.2	25	125
6	2.45	6	14.7	36	216
7	2.64	7	18.5	49	343
8	2.83	8	22.6	64	512
9	3	9	27	81	729
10	3.16	10	31.6	100	1000

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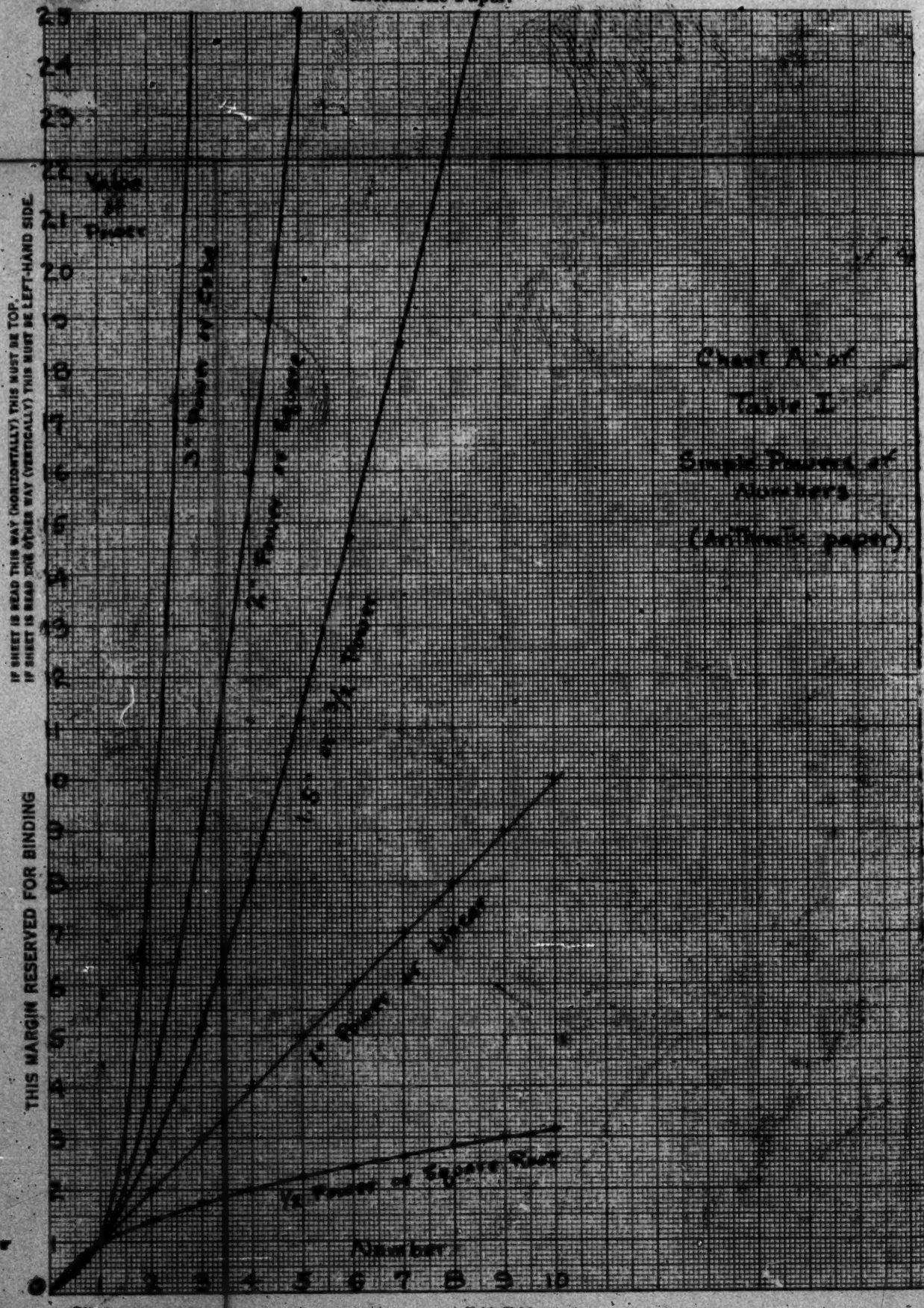
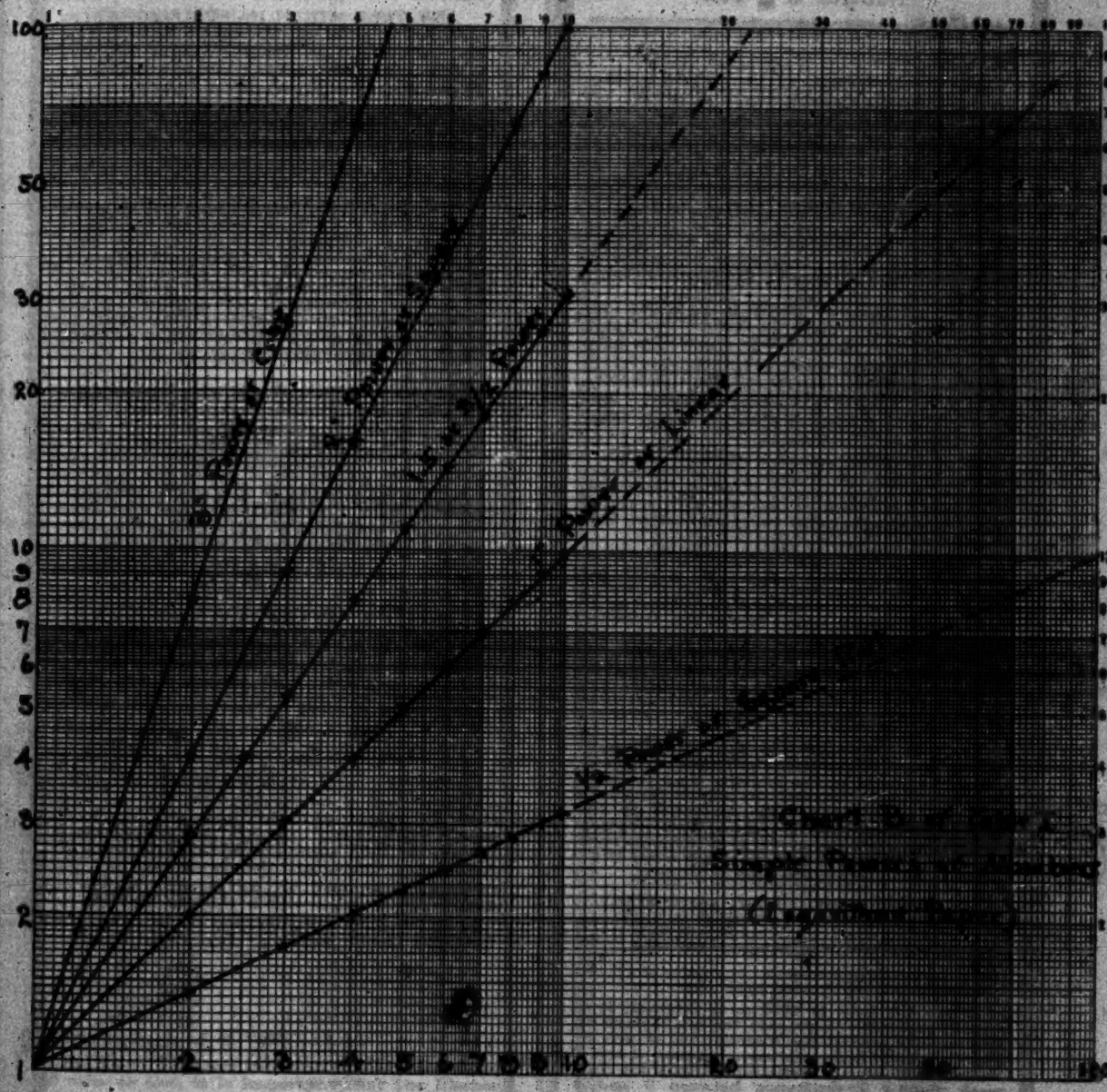
PLAINTIFF'S EXHIBIT No. 14.

Hogan Chart A of Table I, Simple Powers of Numbers, Arithmetic Paper.



PLAINTIFF'S EXHIBIT No. 15.

Hogan Chart B of Table I, Simple Powers of Numbers, Logarithmic Paper.



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PLAINTIFF'S EXHIBIT No. 16.

Plaintiff's UV 199 Tube.

PLAINTIFF'S EXHIBIT No. 16-A.

Data Sheet Enclosed With UV 199 Tube.

RADIOTRON
Model UV-199

RATING

Filament Volts - - -	3.6
Filament Amperes - -	.06
Plate Volts (Maximum) -	90

GENERAL

The filament of Radiotron UV-199 is designed for operation from three No. 6 dry cells in series. Smaller dry cells may be used, but are not so economical. A filament rheostat of at least 30 ohms should be employed with one tube, a rheostat of 20 ohms for two tubes operated in parallel, and a rheostat of 10 ohms for three or more tubes in parallel.

THE FILAMENT SHOULD ALWAYS BE OPERATED AT THE LOWEST VOLTAGE WHICH WILL GIVE SATISFACTORY RESULTS. CARE SHOULD BE TAKEN TO PREVENT THE PLATE VOLTAGE FROM BEING ACCIDENTALLY APPLIED TO THE FILAMENT. REMOVE TUBES FROM SOCKETS WHEN CONNECTIONS ARE CHANGED.

If by accident excessive filament or plate voltage is applied to the tube it may be damaged temporarily. Its normal action may be restored by lighting the filament at rated voltage for 20 minutes or longer with the plate battery disconnected.

Failure of the tube to function is seldom due to burnout unless a very high voltage has been accidentally applied. The end of the useful life of the tube is indicated by a decrease in its operating efficiency which cannot be explained by other causes.

Tubes should be mounted on cushion or spring supports to prevent noise from vibration. It is preferable to mount tubes vertically.

AS AN AMPLIFIER

When Radiotron UV-199 is used as an amplifier, it is important that the filament rheostat should be placed in the negative filament lead, (as shown in Fig. 2), and the return lead from the grid circuit should be connected to the negative side of the battery. This places a negative bias on the grid. For plate voltages above 45, a negative grid biasing battery ("C" Battery) should always be used as follows:

PLATE VOLTAGE	NEG. GRID BIAS
67.5 Volts	1.5—3.0 Volts
90.0 Volts	4.5 Volts

AS A DETECTOR

When the tube is used as a detector, it is usually preferable to connect the grid return to the positive side of the filament, (as shown in Fig. 1). A grid leak resistance between 2 and 5 megohms is usually satisfactory, but for very weak signals a resistance between 5 and 9 megohms is somewhat better. It is preferable to use not more than 45 volts on the plate. Critical adjustment of the plate voltage is not necessary. Leads to the grid should be as short as possible.

RETURN OF DEFECTIVE APPARATUS

ANY TUBE WHICH HAS PROVED DEFECTIVE SHOULD BE RETURNED TO THE DEALER OR DISTRIBUTOR FROM WHOM IT WAS PURCHASED, WHO HAS COMPLETE INSTRUCTIONS FOR HANDLING SUCH CASES.

THE MOST SATISFACTORY RESULTS CAN BE OBTAINED BY THE CONSISTENT USE OF RADIOTRONS IN RADIOLAS.

PATENT NOTICE

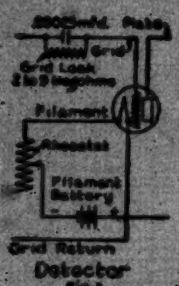
This device is not licensed except for amateur, experimental and entertainment radio use as set forth and to the extent indicated in the current issue of the catalogue of Radio Corporation of America. No express or implied license is granted under any patent owned by the Radio Corporation of America, or under which it is licensed to use or sell this device as an element or part of any combination or organization except as expressly set forth in said catalogue.

Radio Corporation of America

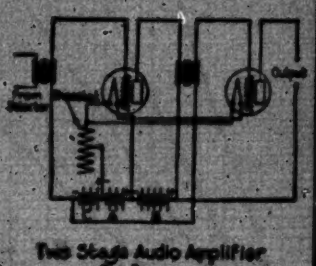
CAUTION!

DO NOT USE EXCESSIVE FILAMENT OR PLATE VOLTAGE.

HANDLE TUBE CAREFULLY.



Detector
Fig. 1



Two Stage Audio Amplifier
Fig. 2

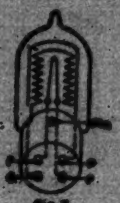


Fig. 3

NP-36346-Rev. 8-15-24

PLAINTIFF'S EXHIBIT No. 17.

Plaintiff's UX 201A Tube.

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PLAINTIFF'S EXHIBIT No. 17-A

Data Sheet Enclosed With UX 201A Tube.

RADIOTRON
Model UX-201-A

RATING

Filament Volts - - - -	5.0
Filament Amperes - - -	.25
Plate Volts (Maximum) - -	135
Plate Volts for Average Use -	90

GENERAL

FILAMENTS SHOULD ALWAYS BE OPERATED AT THE LOWEST VOLTAGE WHICH WILL GIVE SATISFACTORY RESULTS.

If by accident excessive filament or plate voltage is applied to the Radiotron, it may be damaged temporarily. Its normal action may be restored by lighting the filament at rated voltage for 20 minutes or longer with the "B" battery disconnected.

GREAT CARE SHOULD BE TAKEN TO PREVENT THE PLATE VOLTAGE FROM BEING APPLIED ACCIDENTALLY TO FILAMENTS. THE PLATE VOLTAGE SHOULD BE DISCONNECTED BEFORE THE RADIOTRON IS PLACED IN THE SOCKET OR REMOVED FROM THE SOCKET, OR BEFORE ANY CHANGES ARE MADE IN THE CONNECTIONS OF THE CIRCUIT.

Radiotrons should be mounted on cushion or spring supports to prevent noises from vibration. It is preferable to mount Radiotrons vertically.

LARGE STANDARD RADIOTRON BASE

Radiotron UX-201-A is electrically identical with Radiotron UV-201-A. It is equipped with the new large standard Radiotron base (large "UX" base), and the connections to the contact pins are shown in the diagram at the bottom of this sheet.

AS A DETECTOR

When the Radiotron is used as a detector it is usually preferable to connect the grid return lead to the positive side of the filament. A grid leak resistance between 2 and 5 megohms is satisfactory for average work. A resistance between 5 and 9 megohms is somewhat better for very weak signals.

It is preferable to use not more than 45 volts on the plate of the detector tube. Critical adjustment of the plate voltage is not required.

AS AN AMPLIFIER

On Plate Voltages Exceeding 45 Volts

When the UX-201-A Radiotron is employed as an amplifier, a "C" battery should be used whenever the plate potential exceeds 45 volts. The filament rheostat should be placed in the negative lead of the "A" battery, and the grid return lead should be connected to the negative side of the "C" battery. The positive side of the "C" battery is connected to the negative side of the Radiotron filament, as shown in Fig. 1.

PLATE VOLTAGE	NEG. GRID BIAS
67.5 Volts	1.5 - 3.0 Volts
90.0 Volts	3.0 - 4.5 Volts
112.5 Volts	4.5 - 6.0 Volts
135.0 Volts	6.0 - 9.0 Volts

On Plate Voltages of 45 Volts or Less

When no "C" battery is used, and the plate voltage is 45 volts or less, it is important that the filament rheostat should be placed in the negative lead of the "A" battery, and the return lead from the grid circuit should be connected to the negative side of the "A" battery and not to the negative side of the filament. This method places a desirable negative grid bias on the grid.

RETURN OF DEFECTIVE APPARATUS

ANY RADIOTRON WHICH IS BELIEVED DEFECTIVE SHOULD BE RETURNED TO THE DEALER OR DISTRIBUTOR FROM WHOM IT WAS PURCHASED, WHO HAS COMPLETE INSTRUCTIONS FOR HANDLING SUCH CASES.

THE MOST SATISFACTORY RESULTS CAN BE OBTAINED BY THE CONSISTENT USE OF RADIOTRONS IN RADIOLAS.

PATENT NOTICE

In connection with devices it sells, Radio Corporation of America has rights under patents which cover (1) certain devices themselves and (2) certain combinations of the devices with other devices or elements, or for example in various circuits and hook-ups.

The sale of this device carries a license under the patent claims of (1), but only for (2) radiating receiving sets, (3) radio amateur uses, (4) radio experimental uses and (5) radio broadcast reception; and only where no business features are involved.

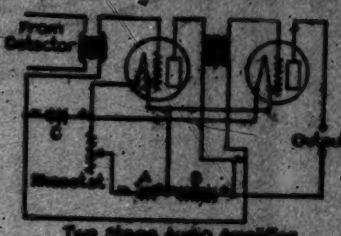
The sale does not carry a license under patent claims of (2) except only (3) for inconsequential commercial uses, operations and systems already licensed for any and such patent claims on considerations, (4) for commissioning by amateurs and experimenters, and not by others, with other licensed parts or devices, or with parts or devices made by themselves, but only for their own amateur and experimental radio uses where no business features are involved, and not for sale to or for use by others, and (5) for use with licensed radiating transmitters and licensed radio broadcast receiving devices, and only where no business features are involved.

Radio Corporation of America

CAUTION!

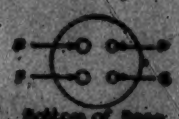
DO NOT USE EXCESSIVE FILAMENT OR PLATE VOLTAGE.

HANDLE RADIOTRON CAREFULLY.



Two stage Audio Amplifier
Fig. 1

Detector
Fig. 2

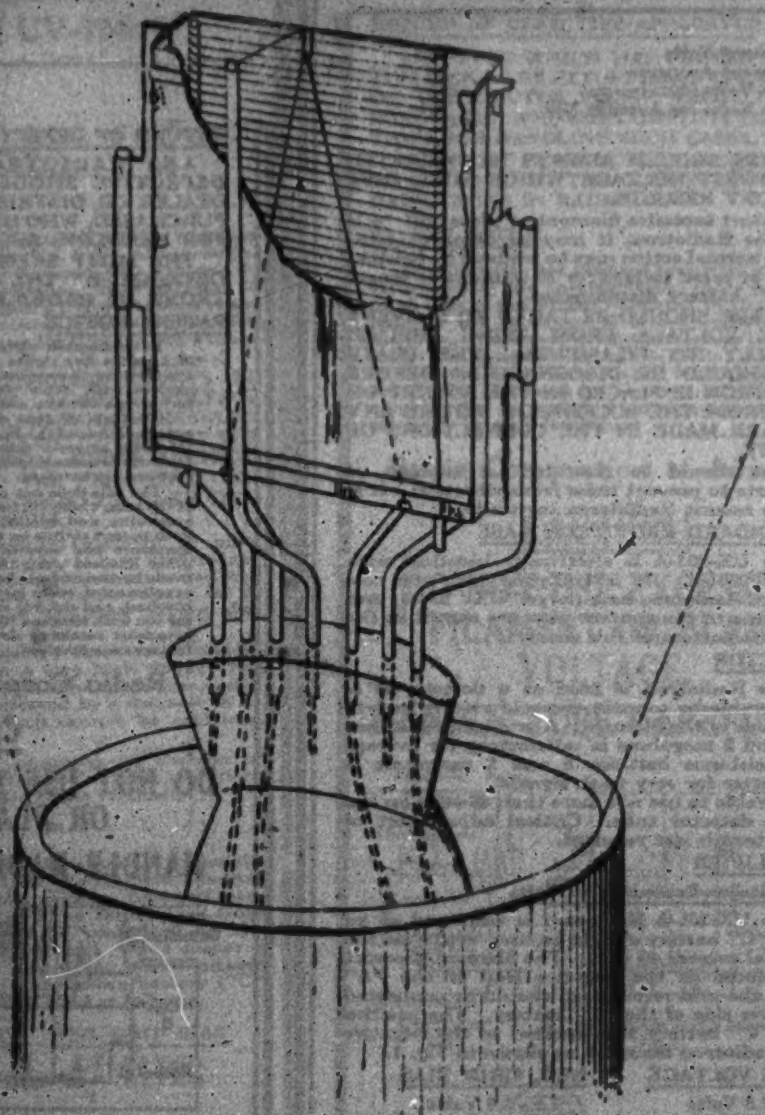


Bottom of Base
Fig. 3

RC-20034 Rev. 11-28

PLAINTIFF'S EXHIBIT No. 18

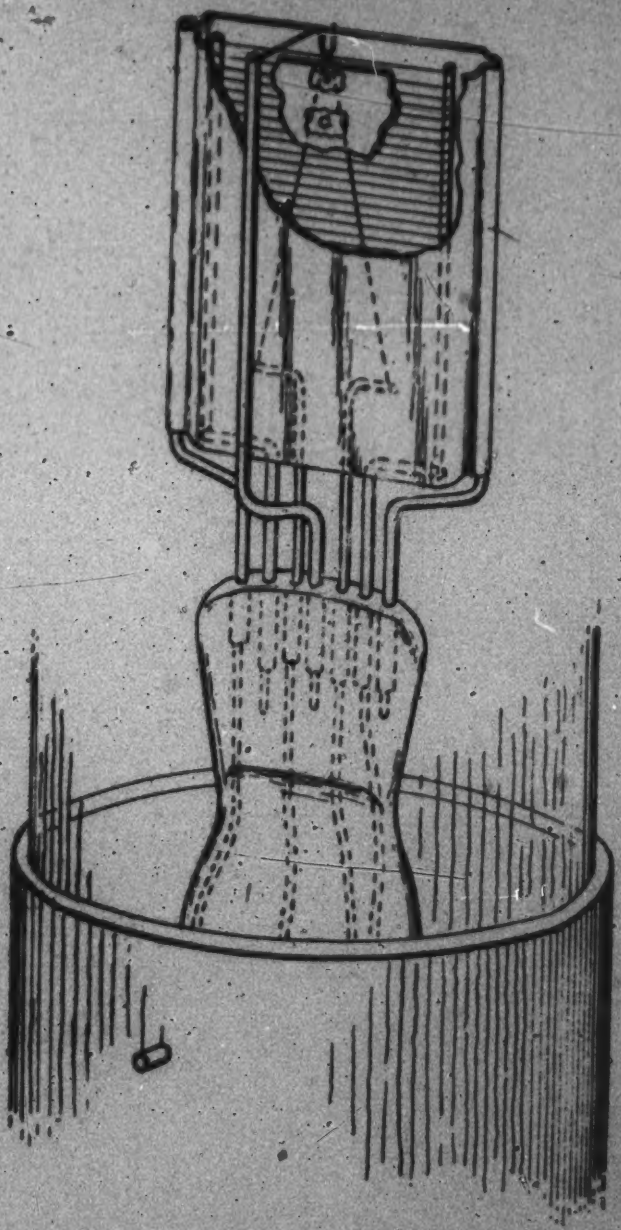
Hogan Drawing Illustrating Plaintiff's UX 201A Tube.



GENERAL ELECTRIC TUBE 201A

PLAINTIFF'S EXHIBIT No. 12.

Hogan Drawing Illustrating Defendant's DV 5 Tube.



DE FOREST TUBE DV5

[NOTE: FOR PLAINTIFF'S EXHIBITS NOS. 20 TO 161 INCLUSIVE, SEE INTERFERENCE RECORD]

PLAINTIFF'S EXHIBIT No. 162.

In the Court of Appeals of the District of Columbia

IRVING LANGMUIR, Appellant,
vs.
HAROLD D. ARNOLD.
No. 1680.
Patent Appeal

OPINION OF THE COURT
(Filed June 1, 1925)

(Before MARTIN, Chief Justice, and ROBB and VAN ORSDEL, Associate Justices).

Appeal from a decision of an Assistant Commissioner of Patents in an interference proceeding awarding priority to the junior party, Arnold, and reversing concurrent decisions of the Examiner of Interferences and the Board of Examiners-in-Chief.

The invention is a thermionic tube adapted to be used as a relay in long distance telephone systems, as a detector or amplifier in wireless systems, or as a rectifier of alternating currents. The issue is expressed in thirteen counts, of which the 1st, 7th and 13th, here reproduced, will serve as examples:

"1. A high vacuum electron discharge device comprising an envelope, an incandescent cathode and an anode, the space in said envelope being evacuated to such degree that the passage of current produces no appreciable positive ionization when the impressed voltage is as high as 200 volts."

"7. A discharge device comprising a tube and electrodes therein one of which is adapted to emit electrons, the degree of evacuation and the relation of the parts of the device being such that the device is capable of being so operated, when volt-

ages materially higher than ionization voltages are impressed on electrodes of the device and when the electron emission has any value such that the space current is below the saturation region at such voltage, that the line obtained by plotting the logarithms of any values of said current below the saturation region as ordinates against the logarithms of the corresponding values of said impressed voltages as abscissae is straight and continuous."

"13. The method of controlling an electric current in one circuit by an electromotive force in another circuit which consists in causing said current at voltages materially above ionization voltages to pass as a discharge across a vacuous space between an electron emitting cathode and an anode, maintaining a high vacuum in said space, governing or limiting the current by a space charge effect in said space substantially unaffected by positive ionization, and superimposing the effect of said electromotive force on said space charge effect to control said current in a stable and reproducible manner."

The attitude of the junior party, appellee here, when this interference was declared, is significant. He filed a motion challenging the patentability of the issue and sought and obtained permission to take evidence in support of that motion. The result was the taking of voluminous testimony by the parties on this issue, which by stipulation is in the record here. The Law Examiner, to whom this question was initially referred, sustained the patentability of the issue and his decision is controlling here. We therefore start our inquiry in this appeal with the established fact that, so far as this proceeding is concerned, the issue is patentable; in other words, that something more than mere mechanical skill was involved in the result achieved.

The Examiner of Interferences, in an exhaustive opinion, awarded priority to the senior party, Langmuir. The Board, on appeal, directed attention to the fact that, structurally considered, the tubes of both parties outwardly are substantially identical with the Fleming valve and the DeForest audion of the prior art; that the invention has been referred to as a "thing compact of glass and metal". The Board then pointed out that

this definition, although correct as far as it goes, is inadequate because it applies equally well to the prior art devices, and that to this definition should be added the qualification that the device "operates with a *pure* electronic discharge above the voltage of positive ionization and below saturation", and proceeded: "But how is one to know whether the discharge is purely electronic? In other words, how is one to know whether a tube embodies merely the prior art devices or the invention of the issue? * * * For example, count 1 specifies that the envelope of the tube is evacuated to such a degree that the passage of current produces no appreciable positive ionization when the impressed voltage is as high as 200 volts. Thus the count distinguishes from the prior art, not by features of structure, but by a characteristic which is manifest while the device is operating at or above a certain voltage."

Later in its decision the Board suggested that the question to be determined was, who of the parties "first knowingly and understandingly conceived and produced such a tube"; that Arnold, the junior party, did not claim to have conceived the invention prior to November 1, 1912, or to have reduced it to practice prior to the 29th of that month; that Langmuir, on the other hand, alleged conception, disclosure, sketches, written description and successful operation prior to September 1, 1912, followed in November of that year by the successful operation of other devices embodying the invention. The Board then carefully reviewed the testimony in support of Langmuir's contentions and found that he had conceived the invention of counts 1 to 11, inclusive, as early as September 1, 1912, and had reduced the same to practice by November 19th of the same year; that, as to counts 12 and 13, Langmuir had conceived prior to April 8, 1913, and had reduced to practice by April 15th of that year; that Arnold conceived and reduced to practice the invention of all of the counts except counts 1 and 11 on April 25, 1913, and that counts 1 and 11 were not reduced to practice until after Langmuir's filing date.

The attitude of the Assistant Commissioner toward the case was that of the junior party upon the declaration of the interference, namely, that the patentability of the issue was doubtful. He says: "The line between the prior art and the issue is attenuated and if there is patentability, it must be as set out in the decision of the Law Examiner on the motion, and I do not understand either party to attack that decision here. Arnold alleges that when he made the invention, he thought he was following the prior art and not producing something patentable, and an undercurrent of that attitude seems to tinge his whole case. This is why he filed so late." Proceeding from that postulate, the Assistant Commissioner has accepted as controlling on the question of conception and reduction to practice, on behalf of Arnold, testimony of a vague and general character and which failed to satisfy the lower tribunals, as it also has failed to satisfy us. The decisions of those tribunals are so clear and satisfying that we are content to rest our opinion upon the reasoning there given.

It results that the decision is reversed and priority awarded Langmuir.

Reversed.

CHAS. H. ROBB,
Associate Justice.

Endorsed: No. 1680 Patent Appeal. Irving Langmuir, Appellant, vs. Harold D. Arnold. Opinion of the Court per Mr. Justice ROBB. Court of Appeals, District of Columbia. Filed June 1, 1925. HENRY W. HODGES, Clerk.

A true Copy.

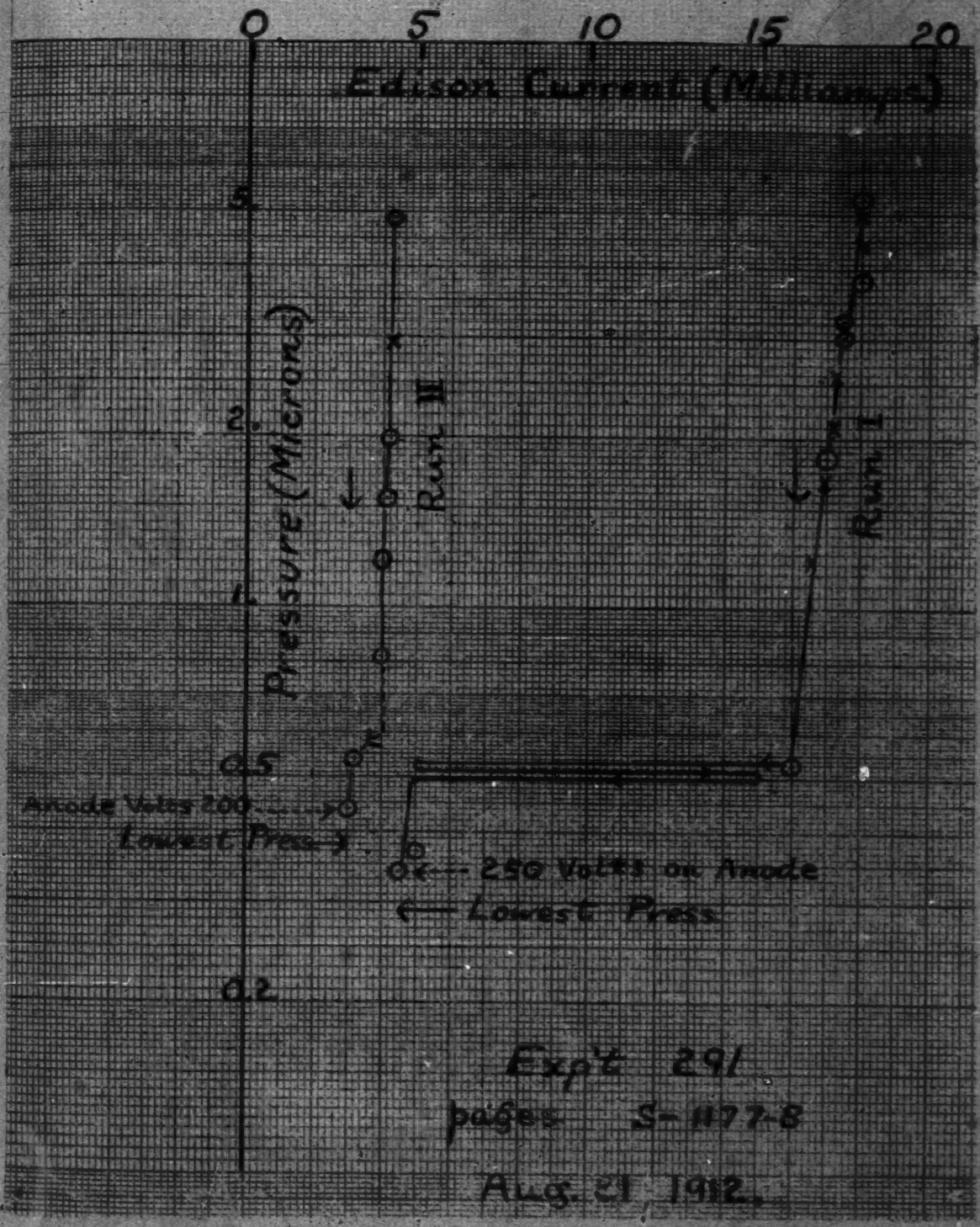
Test: HENRY W. HODGES,

[SEAL] Clerk of the Court of Appeals of the District of Columbia.

PLAINTIFF'S EXHIBIT No. 163.

Langmuir Explanatory Diagram.

MPANY, SCHENECTADY, N. Y., U. S. A.



Expt 291

pages S-477-8

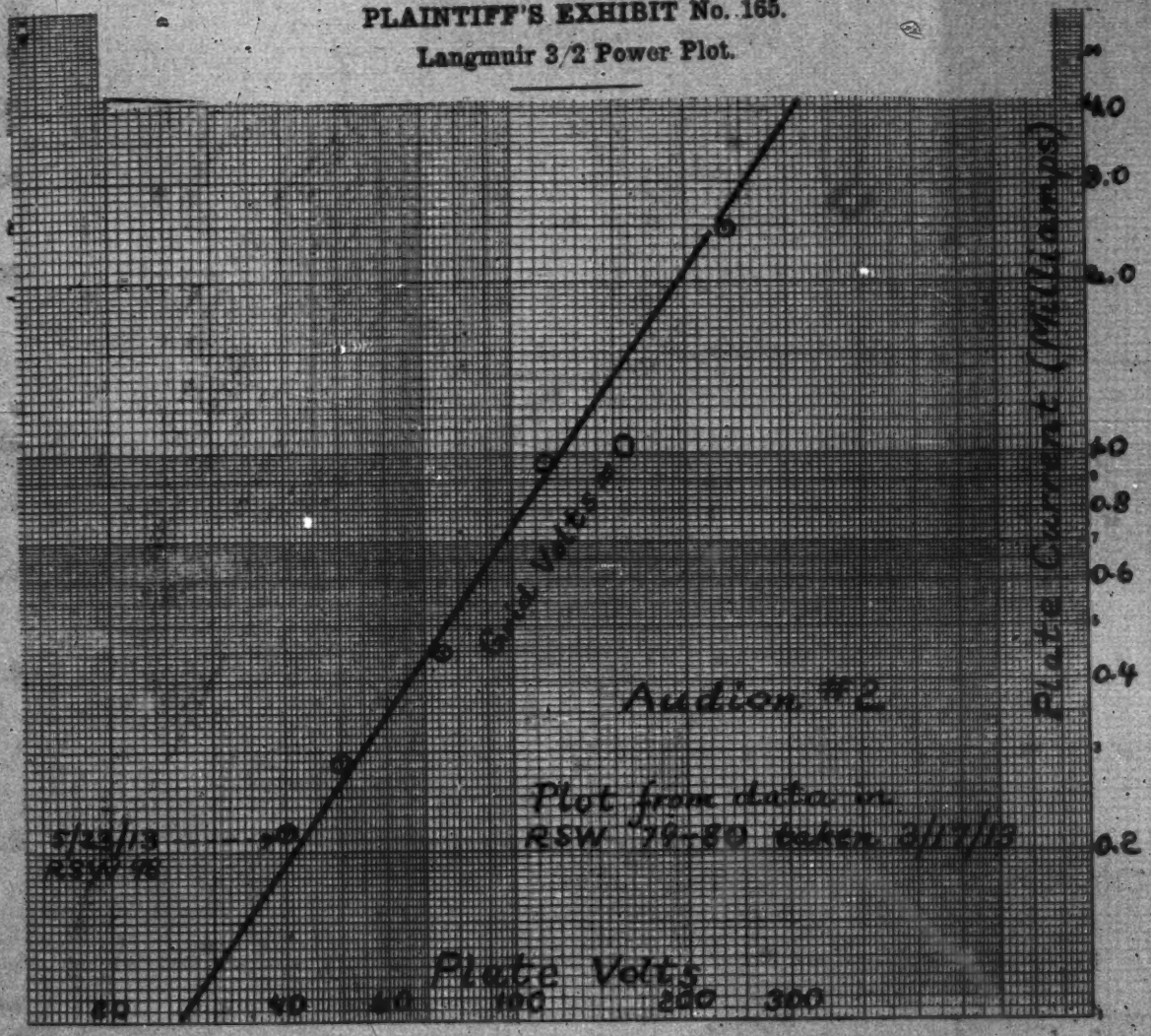
Aug. 21, 1912.

PLAINTIFF'S EXHIBIT No. 164.

Langmuir 2/3 Power Plot.

PLAINTIFF'S EXHIBIT No. 165.

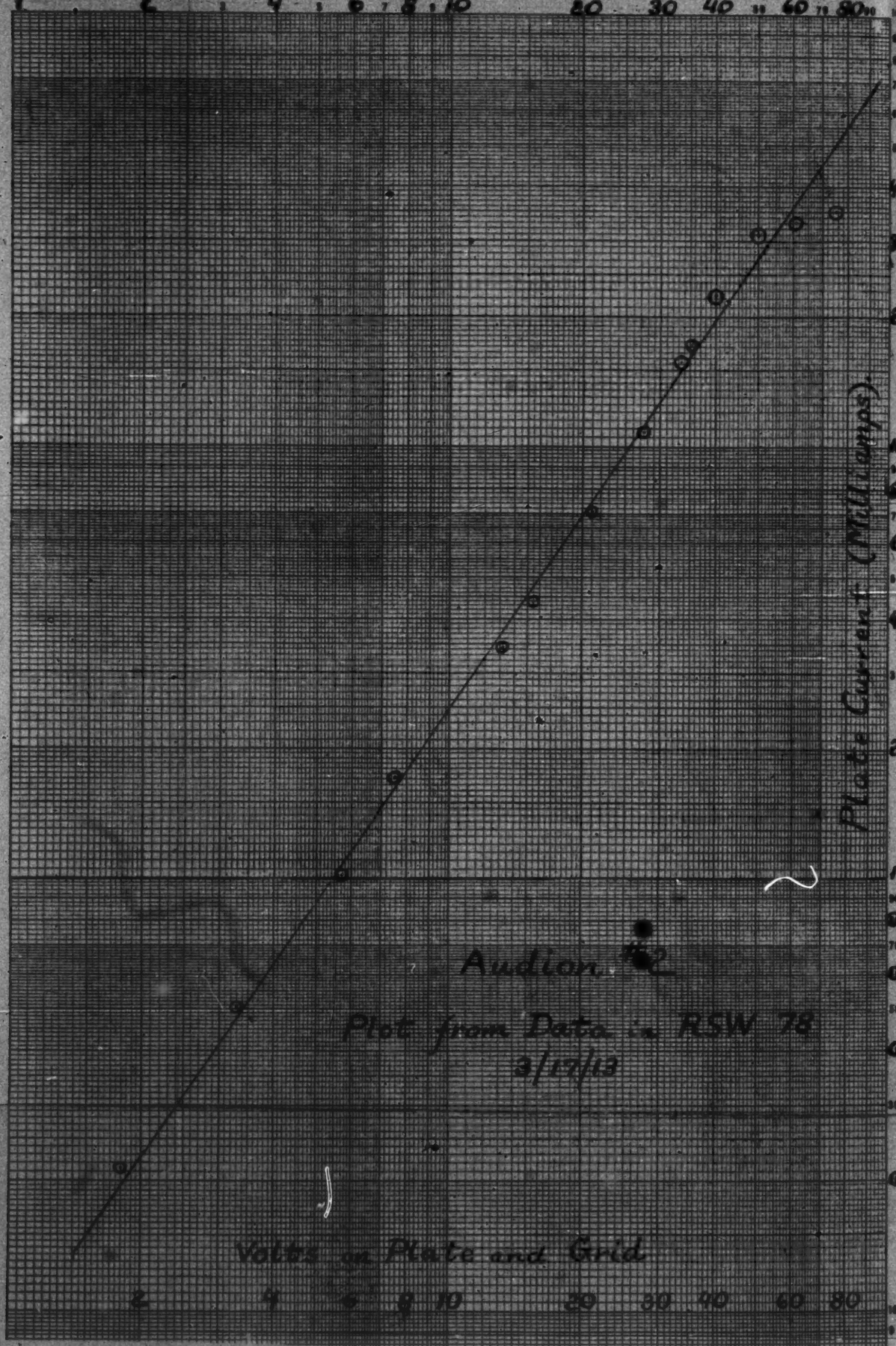
Langmuir 3/2 Power Plot.



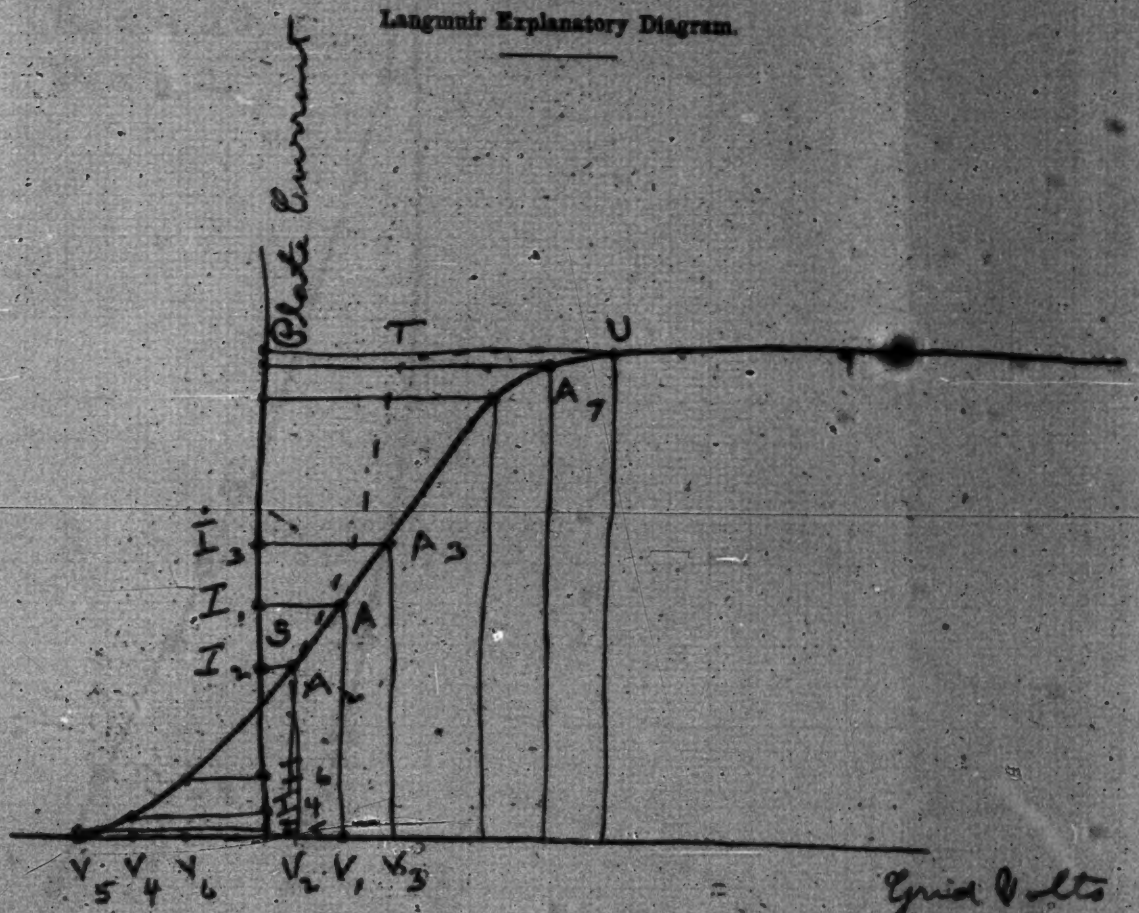
IS MARGIN

Langmuir Plot of Volts on Plate and Grid Against Current Audion No. 2.

BE TOP.
JST BE LEFT.



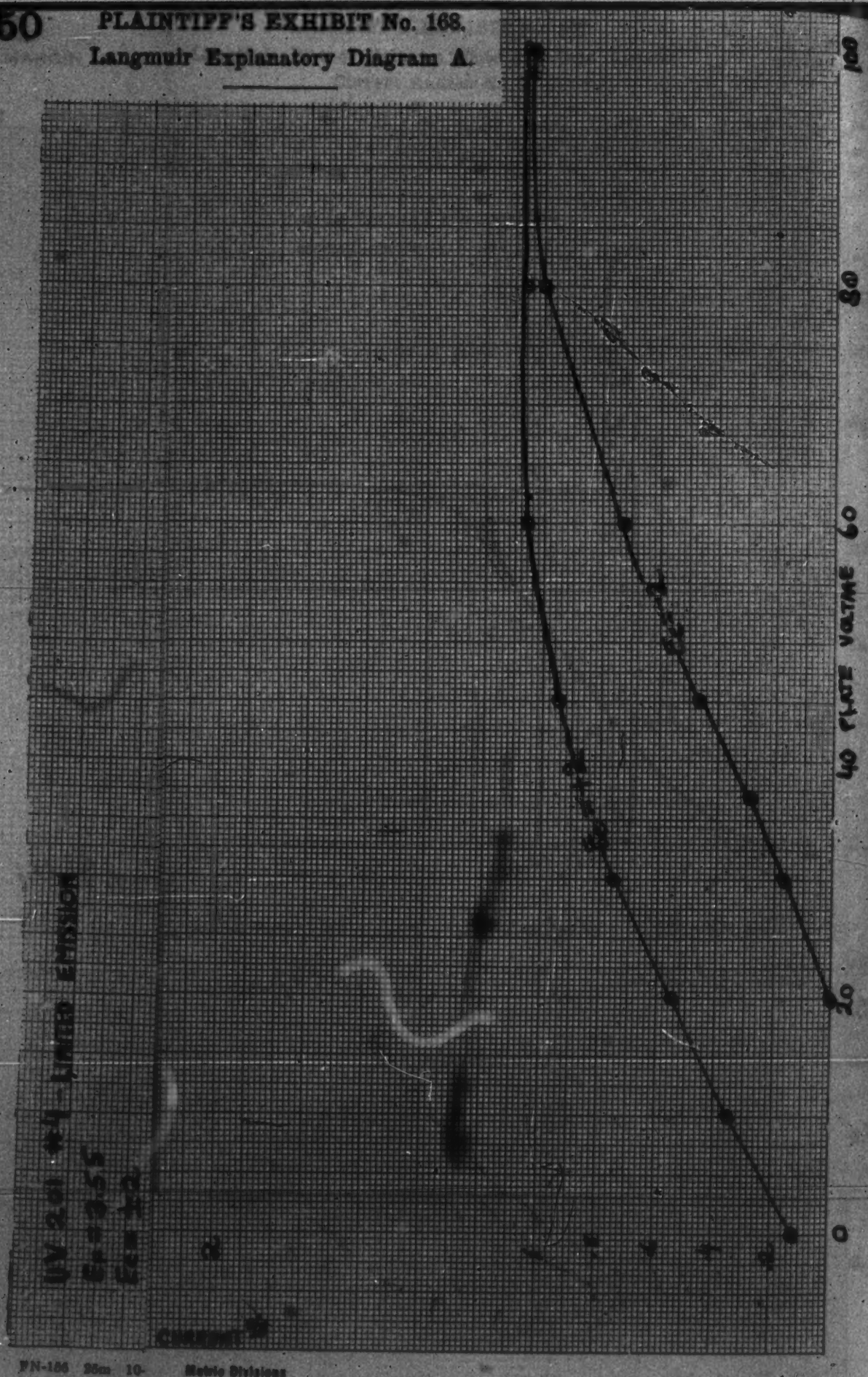
PLAINTIFF'S EXHIBIT No. 147.
Langmuir Explanatory Diagram.



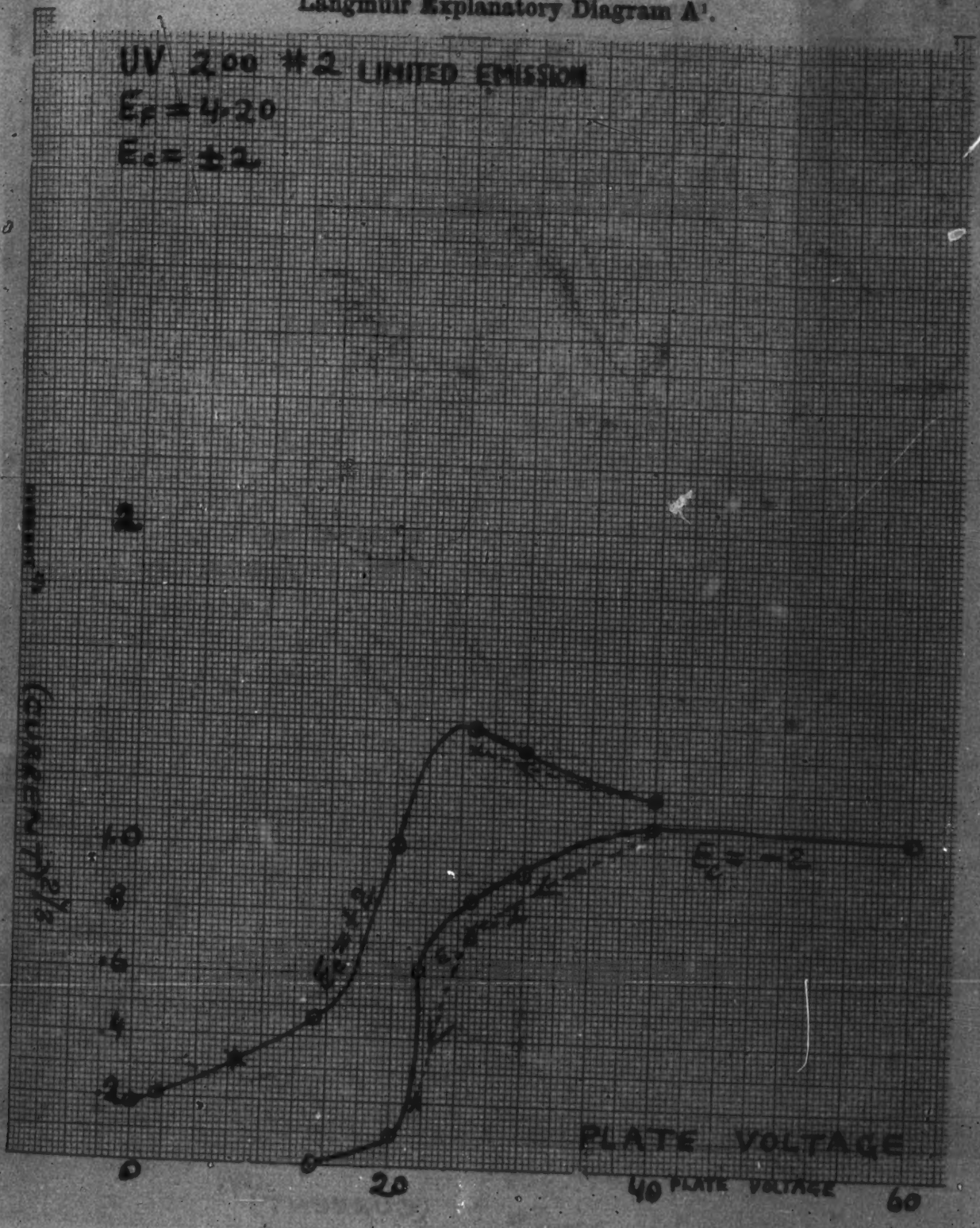
Detector depends on curvature.
Amplifier " " slope

50 PLAINTIFF'S EXHIBIT No. 168.

Langmuir Explanatory Diagram A.

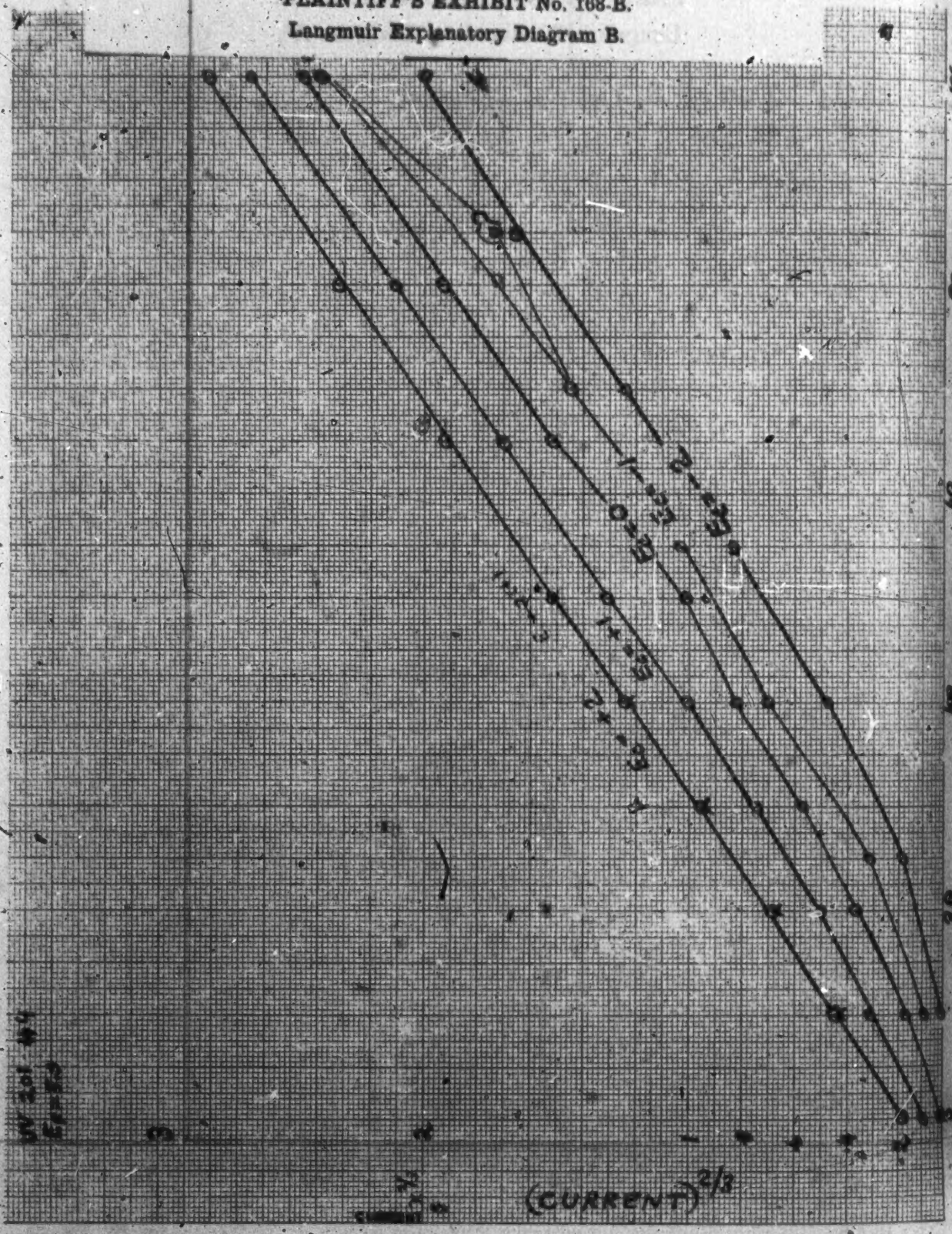


PLAINTIFF'S EXHIBIT No. 168-A.
Langmuir Explanatory Diagram A'.



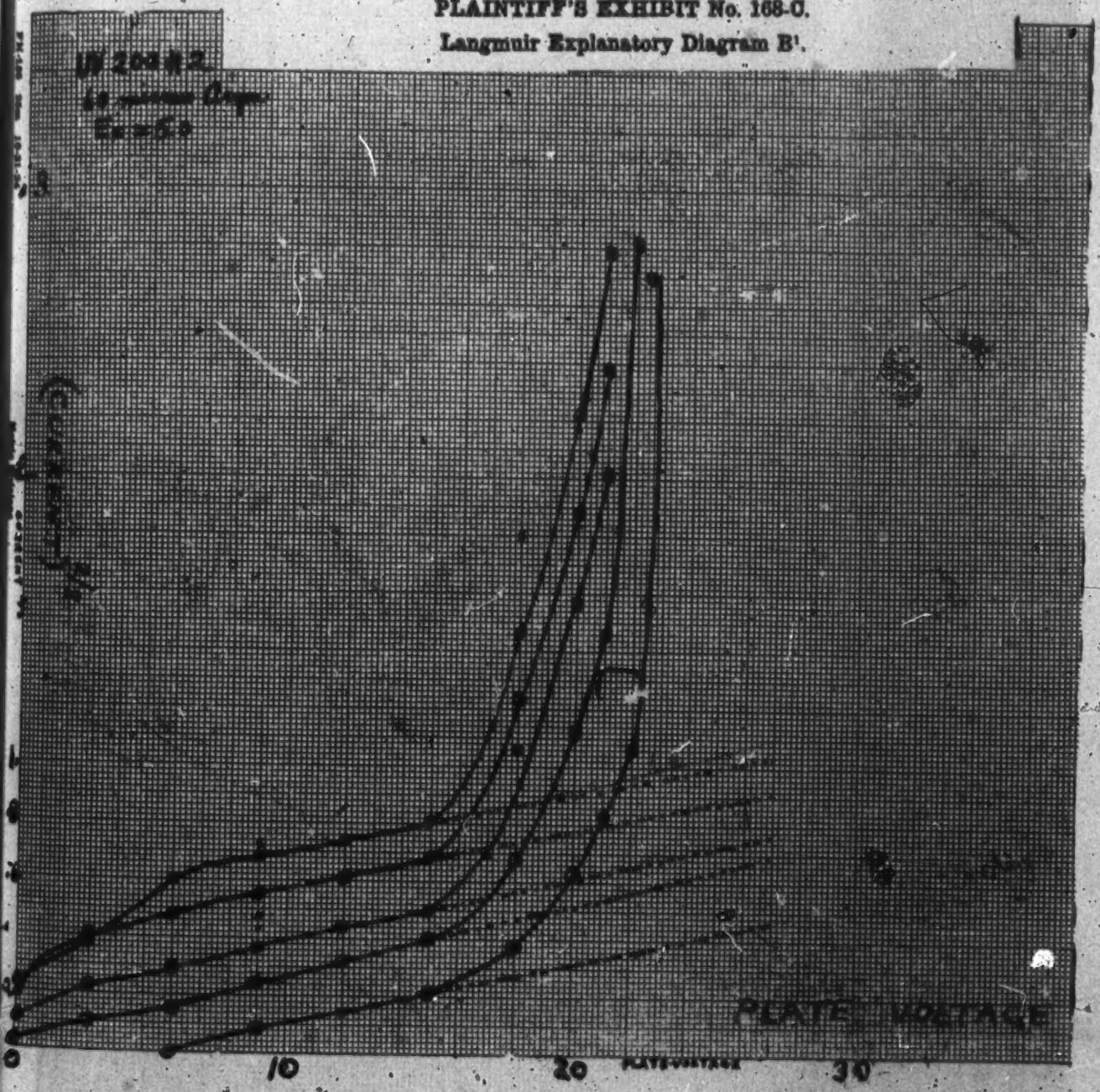
PLAINTIFF'S EXHIBIT No. 168-B.

Langmuir Explanatory Diagram B.



FN-156 25m 10-31-24 Metric Divisions

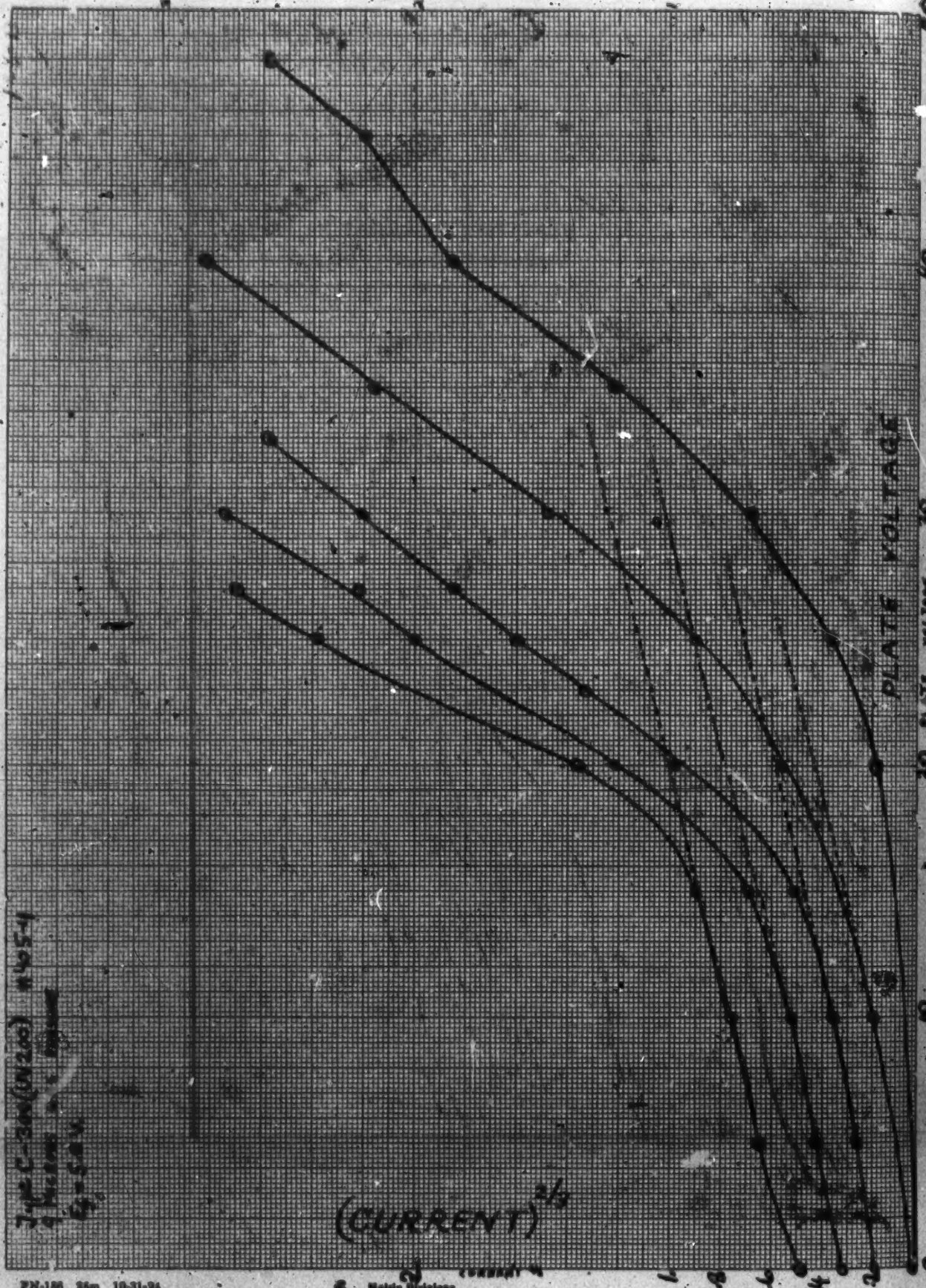
PLAINTIFF'S EXHIBIT No. 168-C.
Langmuir Explanatory Diagram B'.



GENERAL

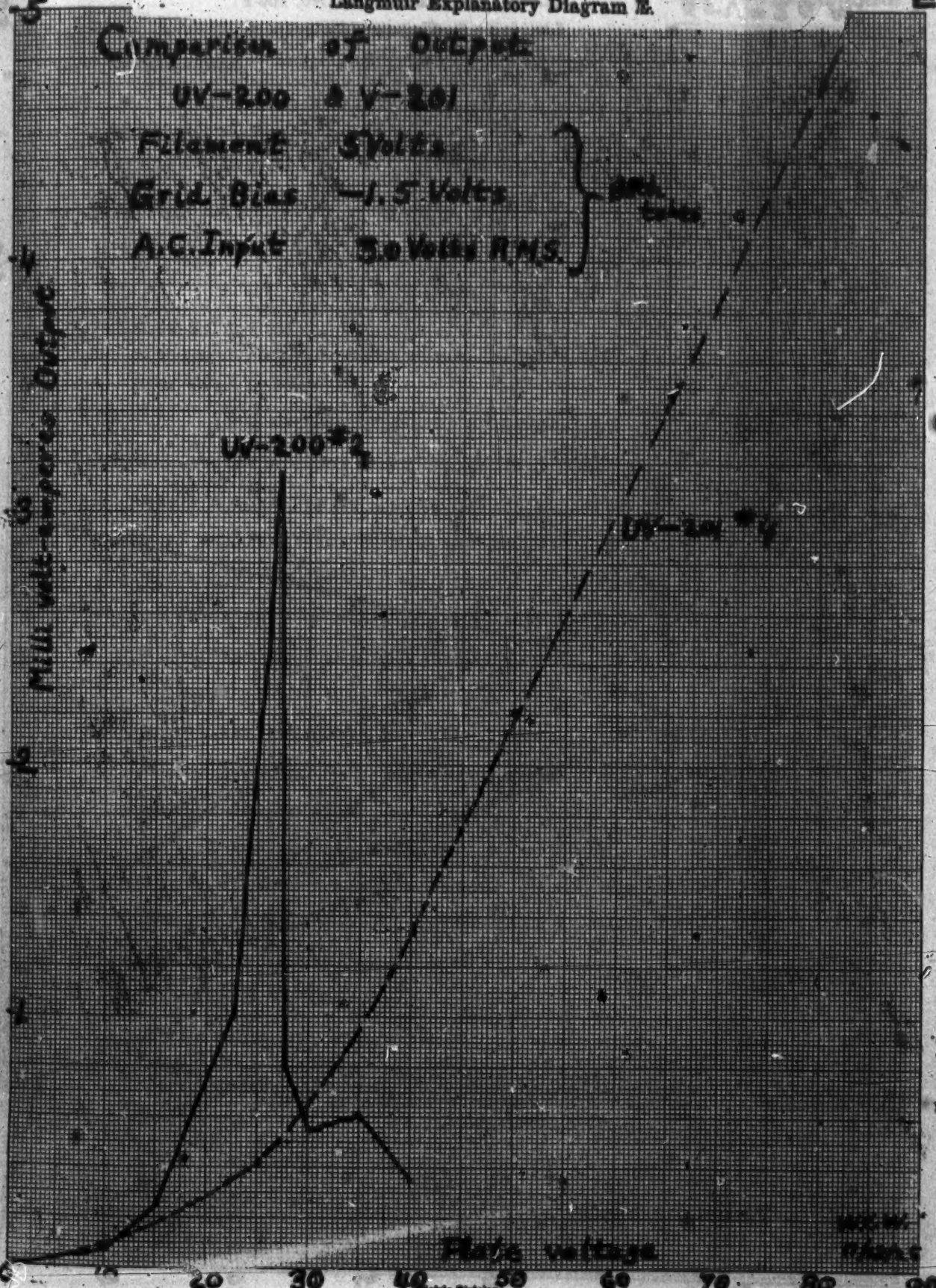
PLAINTIFF'S EXHIBIT No. 168-D.

Langmuir Explanatory Diagram D.

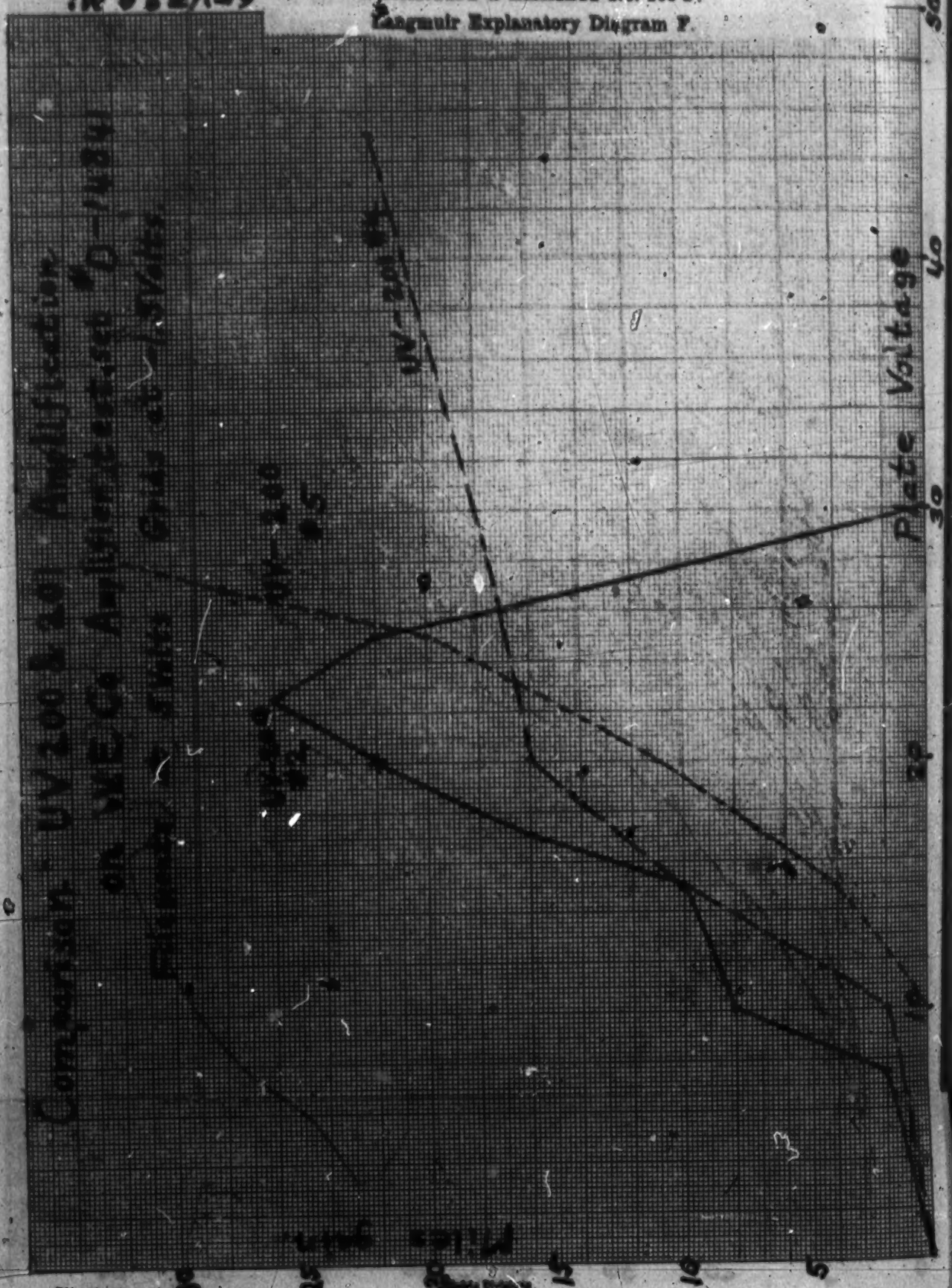


GENERAL ELECTR

PLAINTIFF'S EXHIBIT No. 168-E.
Langmuir Explanatory Diagram E.



PLAINTIFF'S EXHIBIT No. 168-F.
Langmuir Explanatory Diagram F.



ERAL ELECTRIC COMPANY PLAINTIFF'S EXHIBIT No. 169.

EXECUTIVE CORRESPONDENCE

Subject:

Location:

Referring to:

Attention of:

Atty Docket 1605 Feb 7/13

Schenectady, N. Y. Feb. 5, 1913.

Miss H. Orford,
Patent Department.

Dear Miss Orford:

As a matter of record of conversation with Mr. Hawkins and Dr. Coolidge on Jan. 9th, please docket a case for me on the use of an X-ray tube as an amplifier for high frequency current for wireless telegraphy. In the incandescent rectifier which is sometimes used as a detector, relay action is obtained by introducing the controlling potential on a grid which is placed in the flow of the radiating energy. The controlling potential has the effect of starting and stopping the flow and this principle may be app lied on a large scale as an amplifier for sending purposes.

I have a patent used sometime ago covering broadly the use of this principle in combination with telephone for sending wireless telephone messages.

This particular construction of the X-ray tube suggested to me the possible advantages of deflection, rather than stopping the flow of energy by providing two targets and deflecting the flow of energy from the antenna circuit to

the local circuit. The deflection may be produced either by electro-magnet which is controlled by the telephone or by an electrostatic potential.

A. Ellen Orford
17605f
Feb 7/13

Yours very truly,

C.F. Alexanderson

PLAINTIFF'S EXHIBIT No. 170.

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE

To all persons to whom these presents shall come, Greeting:

THIS IS TO CERTIFY that the annexed is a true copy from the records of this office of the File Wrapper, Contents and Drawing, in the matter of the

Letters Patent of

Harold D. Arnold, Assignor, by Mesne Assignments to Western Electric Company, Incorporated,

Number 1,297,309, Granted March 18, 1919,

for

Improvement in Manufacture of Vacuum-Tube Devices.

IN TESTIMONY WHEREOF I have hereunto set my hand and caused the seal of the Patent Office to be affixed, at the City of Washington, this third day of November in the year of our Lord, one thousand nine hundred and twenty-six and of the Independence of the United States of America the one hundred and fifty-first.

ATTEST: Willis R. Ringueder
Chief of Division.

Thomas E. Robertson
Commissioner of Patents.

60

NUMBER (Series of 1915).
62259

1915

(EX'R'S BOOK) 143-344-7

DIV. 51 16

PATENT No. 1297309

Name Harold D Arnold
Assignor to Western Electric Company Incorporated
a corp. of ~~Illinois~~ New York

of East Orange
County of
State of New Jersey
Invention Manufacture of Vacuum Tube Devices

DATES OF APPLICATION FILED	ORIGINAL	RENEWED
Petition	Nov. 18, 1915	, 191
Affidavit	" " , 1915	, 191
Specification	" " , 1915	, 191
Drawing	√ , 1915	, 191
Photo Copy	, 191	, 191
First Fee Cash #15	Nov 18, 1915	, 191
" " Cert.	, 191	, 191
Appl. filed complete	Nov. 18, 1915	, 191
		, 191
Examined and Passed for Issue	Mar. 12, 1918	, 191
Examiner	A D Cousins Exr. Div. 16	Exr. Div.
Notice of Allowance	Dec. 16, 1918	, 191
Final Fee Cash	Exp. Feb. 7 1919	By Commissioner
" " Cert.	, 191	, 191
		, 191
Patented	MAR 18 1919	, 191

Division of Appl. No. 7

Attorney De Witt & Tanner 3rd John G. Roberts
46 Wall St. New York, NY
920 Broadway
N. Y.

Associate Attorney

(No. of Claims Allowed 4) Title as Allowed Manufacture of Vacuum Tube Devices (as Amd)

Cl. 250-27

62.2 61

DIV.

NOV 10

To the Commissioner of Patents:

Your petitioner, HAROLD D. ARNOLD,

citizen of the United States, residing at East Orange in the County of Essex and State of New Jersey, whose post-office address is 140 South Munn Avenue, East Orange, New Jersey, prays that Letters Patent may be granted to him for the improvement in MANUFACTURE OF VACUUM TUBE DEVICES, set forth in the annexed specification; and he hereby appoints DE WITT C. TANNER (Reg. No. 4325) and JOHN G. ROBERTS (Reg. No. 9064) of No. 463 West Street, New York, New York, severally, his attorneys, with full power of substitution and revocation, to prosecute said application, to make alterations and amendments therein, to receive the patent, and to transact all business in the Patent Office connected therewith; and requests that communications from the Patent Office in connection with this application be addressed to said JOHN G. ROBERTS.

Harold D. Arnold

25

Case 15

TO ALL WHOM IT MAY CONCERN:

Be it known that I, HAROLD DE FOREST ARNOLD, a citizen of the United States, residing at East Orange, in the County of Essex and State of New Jersey, have invented certain new and useful improvements in the MANUFACTURE OF VACUUM-TUBE DEVICES, of which the following is a full, clear, concise, and exact description.

This invention relates to the manufacture of vacuum tube devices,

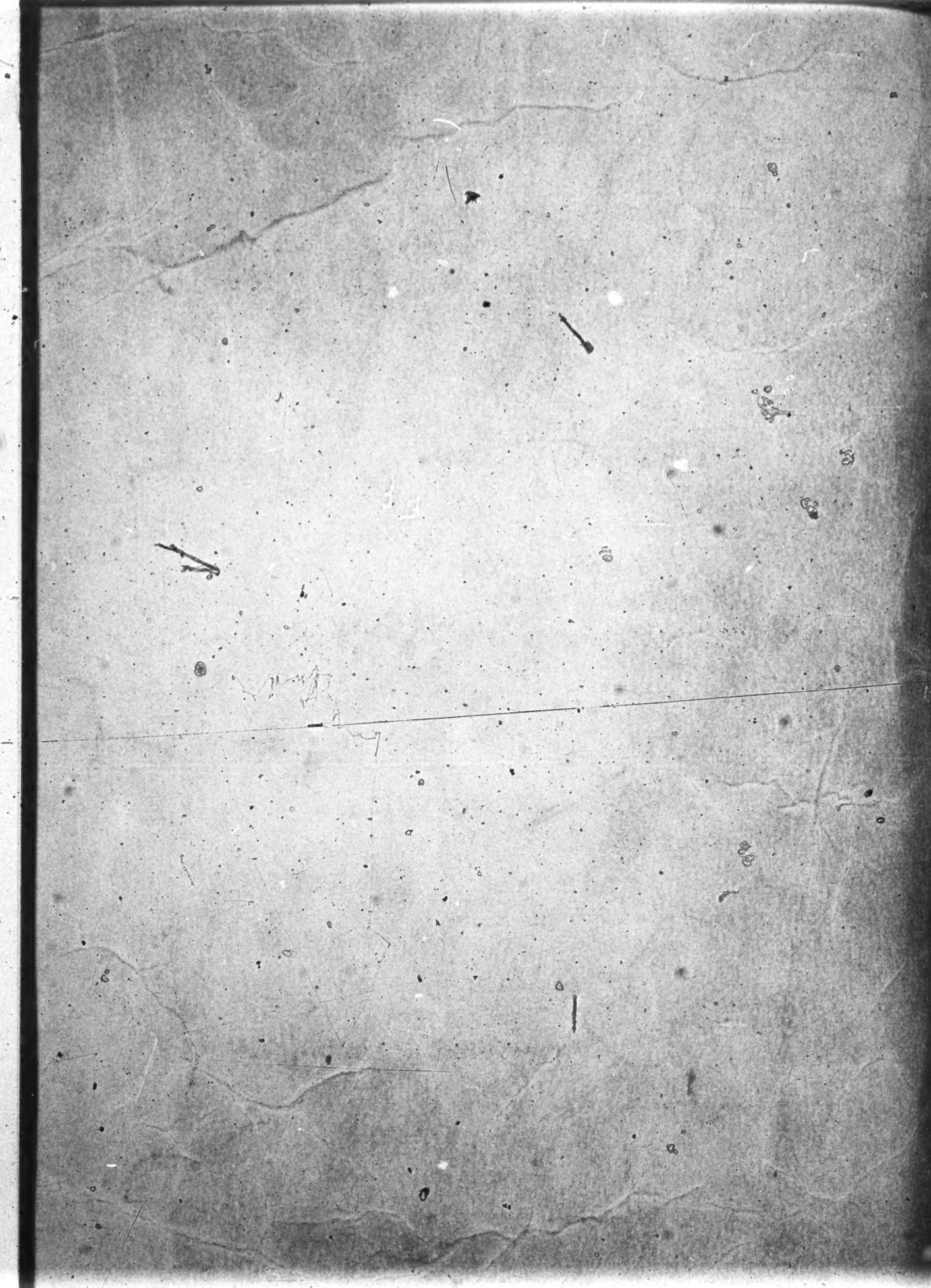
and more particularly it relates to a method of exhausting air and other gases and vapors from the glass bulbs or containers which enclose the electrode elements of thermionic repeaters, such as audions, and similar devices in which extremely high vacua are desired.

Its objects are an effectively complete elimination of the gases occluded by the walls of the containing vessel, and by the electrode elements and other metallic surfaces enclosed therein, a removal of such gases or any other gases from the containing vessel, and a resulting product characterized by stability and uniformity of operation.

To these ends this invention provides for the attachment of the vessel to be exhausted to any suitable vacuum pump and for the application of heat to the exterior of such vessel during the process of evacuation. It further provides for the heating of one or more of the enclosed electrodes by the passage of an electric current therethrough, and for the production in said vessel of an electron discharge which may be made to bombard and heat another electrode through the application of a suitable potential difference between the said electrode and the source of said discharge.

A more complete understanding of the method of this invention will be obtained by consideration of the attached drawing, which illustrates an apparatus arrangement suitable for producing the high vacua desired in thermionic devices of the audion type. It will, of course, be appreciated that the method herein disclosed is equally applicable to the production of high vacua in any device having an electrode or electrodes capable of producing an electron discharge.

In the drawing, a plurality of thermionic repeater elements 2, each having the customary filamentary cathode 3, grid 4 and anode 5, are enclosed in an oven 6 which may be electrically heated by a resistance element 7 connected to a suitable source of current 8. The glass containing-vessels 9 of the elements 2 have tubular extensions 10 connected to a main tube 11 leading to an exhaust apparatus 12, such, for example, as a Gaede molecular pump, connected to a source of motive power 13. The terminals of the electrode elements 3, 4 and 5 are brought out through suitable apertures 14 in one of the walls of the oven 6, so as to be readily available for test purposes and for the application of any desired electromotive force. A suitable number of windows 15 are provided in the front of the oven 6 so that the appearance of the tubes 2 being exhausted may be observed during the process. The filaments 3 are connected in series with a source of current 16 and a variable resistance 17. The process of exhausting the vessels 9 is as follows: The pump 12 is started and the temperature of the oven 6 is gradually raised until it has reached approximately 450° C. The purpose of this heating is to drive out the gases occluded by the walls of the vessel 9. After the temperature of the oven has risen to about 250° C., the filaments 3 are brought to incandescence by current supplied from the source 16, which current is raised to a value approximately 10% greater than the current normally to be used in the operation of the completed device. A potential difference is thereupon successively applied to the terminals of the electrodes 4 and 5 by means of a test clip 20 connected through the potentiometer 21 to a direct current source 22 of about 220 volts output. The filament 3 being



connected to the negative terminal of the source 22 as shown, and the test clip 20 being connected to the positive terminal of the source 22, there will result an electron discharge from the cathode 3 to the electrode 4 or 5, to which the test clip 20 is temporarily connected. This potential difference is made sufficiently high, through adjustment of the potentiometer 21, to cause an electron discharge of sufficient volume to heat the electrode to which the test clip 20 is attached, even to incandescence, which heating is effective to drive out any gases which may be occluded by said electrode.

The electron discharge, which passes from the cathode 3 to either electrode 4 or 5 when a potential difference is established therebetween, partially ionizes whatever gas may be in its path. When gas in sufficient quantity is thus ionized, there will result a blue glow in part or all of the vessel 9, which may readily be observed through one of the windows 15. The intensity of this blue glow depends upon the amount of gas present and upon the current and potential difference impressed between the cathode 3 and electrode 5. For a given current and potential difference therefore, this blue glow will gradually become fainter as the gas within the vessel becomes more attenuated, until the glow finally disappears.

A visible indication of the sufficiency of evacuation is therefore available, and, for example, in exhausting the bulbs of thermionic repeaters, such as are employed in telephone work, it has been found that a sufficiently high vacuum has been obtained if the blue glow no longer appears, when approximately 176 volts potential difference is impressed between the cathode 3 and the anode 5. When this point has been reached, the tubes

are allowed to cool gradually and are sealed off of the pump 12 and given an aging run, which consists in applying the normal heating current to the filaments 3 and impressing the customary operating potential difference between the cathode 3 and anode 5. It has been found that after an aging run of from fifteen to twenty hours duration, for example, the repeaters have reached a stable condition and may be relied upon to give constant and uniform results.

In case the thermionic device to be exhausted is equipped with a grid 4 of very fine mesh, as in the case of a repeater designed for voltage amplification, it may be difficult to obtain a current to the electrode 5 sufficient to heat it properly. In such an event, it has been found desirable to apply an additional positive potential from a source 23, for example of perhaps 60 volts output, to the grid electrode 4 at the same time that the positive potential from source 22 is being applied to the anode 5. This increases the flow of electrons to the anode 5, and as some current will also flow between the filament 3 and grid 4, the voltages may be adjusted so as to heat both electrodes 4 and 5 at the same time.

With some tubes the early part of the process may be accelerated by applying to both the grid electrode 4 and the anode 5 the same large potential as that which later in the process is applied to the anode only.

WHAT IS CLAIMED IS:

1. The method of producing a high vacuum in a thermionic discharge tube, which consists in establishing an electron discharge within said tube during the process of evacuation and causing said discharge to bombard an electrode element within said tube, thereby heating said electrode and driving out the gases occluded thereby.

2. The method of producing a high vacuum in a thermionic discharge tube containing a plurality of electrodes, which consists in heating one of said electrodes to incandescence and simultaneously establishing an electron discharge between said electrode and a second electrode, whereby said second electrode is heated and its occluded gases are expelled.

3. The method of producing a high vacuum in a thermionic discharge tube, which consists in applying heat to the exterior of said tube during the process of evacuation and in establishing an electron discharge within said tube and causing said discharge to bombard and heat an electrode within said tube and to drive out the gases occluded thereby.

4. The method of producing a high vacuum in a thermionic discharge tube containing three electrodes, which consists in heating one of said electrodes to incandescence and establishing an electron discharge between two of said electrodes whereby one of said electrodes is heated during the process of evacuation, and in assisting the passage of said discharge by means of a potential different third electrode.

5. The method of producing a high vacuum in a thermionic discharge tube containing three electrodes which consists in heating one of said electrodes to incandescence and establishing an electron discharge between one of said electrodes and the other two electrodes during the process of evacuation, whereby said two electrodes are heated by bombardment and their occluded gases are driven off.

In Witness Whereof, I hereunto subscribe my name this Fifteenth day of November A. D., 1915.

Harold D. Arnold

WITNESSES:

State of New York }
COUNTY OF New York } ss.:

HAROLD D. ARNOLD, the above named petitioner, being duly sworn, deposes and says that he is a citizen of the United States, and resident of East Orange in the County of Essex and State of New Jersey and that he verily believes himself to be the original, first, and sole inventor of the improvement in MANUFACTURE OF VACUUM TUBE DEVICES described and claimed in the annexed specification; that he does not know and does not believe that the same was ever known or used before his invention or discovery thereof, or patented or described in any printed publication in the United States of America or any foreign country before his invention or discovery thereof, or more than two years prior to this application, or in public use or on sale in the United States for more than two years prior to this application and that no application for foreign patent has been filed by him or his legal representatives or assigns in any foreign country.

Harold D. Arnold

Sworn to and subscribed before me this 15th day of November 1915.

Notary Public.

NOTARY PUBLIC
NEW YORK COUNTY No. 287,
NEW YORK REGISTER No. 7245

Div. 37 Room 107 S-389 Paper No. 2. 26

Address "The Commissioner of Patents, Washington, D. C." and not any official by name.

All communications regarding this application should give the serial number, date of filing, official designation, and name of the applicant.

W.C.----W.T.

DEPARTMENT OF THE INTERIOR

UNITED STATES PATENT OFFICE

WASHINGTON Apr. 25, 1916.

U.S. PATENT OFFICE APR 25 1916 MAILED

John G. Roberts,

463 West St.,

New York City.

Please find below a communication from the EXAMINER in charge of the application of

E. D. Arnold: Manufacture of Vacuum Tube Devices; Nov. 18, 1915; #62,259.

Thomas Ewing
Commissioner of Patents.

The claims are rejected on British patent #15,788 of 1914, accepted Oct. 1, 1915 (three sheets of drawing); also on

Snook, 1,166,792; Jan. 4, 1916; filed Oct. 8, 1912; Class 176-2.

W. S. Ruckman
Examiner.

See carbon of applicants.

Cl 1

UNITED STATES PATENT OFFICE
Division 37, Room 107

In re application of
HAROLD DeF. ARNOLD,
Serial No. 68,259
Filed Nov. 19, 1918

Manufacture of Vacuum Tube Devices.

COMMISSIONER OF PATENTS,

Washington, D. C.

Sir:-

This amendment is in response to the Office action of April 25, 1916. Please amend the application as follows:

Cancel claims 1 and 3 and renumber the remaining claims as 1, 2 and 3:

In present claim 2, line 3, after "consists" insert -in heating one of said electrodes to incandescence,-; cancel line 4, and substitute the following: --said heated electrode and a second one of said electrodes whereby said second electrode is--.

Present claim 3, line 3, after "consists" insert -in heating one of said electrodes to incandescence,-; line 4, cancel "one of said electrodes" and insert -said electrode-.

REMARKS

Rejection of present claim 1 upon the patent to Snook is thought to be an error, for Snook does not use an electrode which can be heated to incandescence in the manner explained in this application. Snook shows two cold electrodes K and a, one of which may be heated by bombardment to a certain degree, but certainly not to such a temperature as is understood by the term "incandescence". Applicant has in mind and clearly explains in his application that one electrode is to be heated

(Serial No. 62,259)

to incandescence by an electric current and as a result of this high heating will give off its occluded gas and at the same time will constitute a source of electrons which may then be driven to a second electrode to heat and bombard this second electrode in such a manner as to drive off its occluded gas. No such process is intimated or is even possible in Snook's arrangement.

It is thought that present claim 2 is allowable in the form in which it was submitted, but in order to more fully distinguish from the patent to Snook, the claim has been limited by including the step of heating one of the electrodes to incandescence. It is to be emphasized that this claim sets forth a process particularly adapted for use in a vacuum discharge tube where one electrode may act as a serious barrier to the establishment of a fairly large electron stream to a third electrode. The claim points out that the step for overcoming the difficulty consists in applying a potential difference between the source of discharge, which is now defined as the incandescent electrode and thereby establishing an electron stream or discharge between said incandescent electrode and the impeding electrode. With this explanation as to this claim 2, it is thought that the claim will be found allowable.

Claim 5 has been amended to distinguish from Snook by inserting the step of heating one of the electrodes to incandescence, and as pointed out in connection with claim 1, this electrode is then caused to give up its occluded gas and at the same time to become an electron source, making it possible to establish an electron discharge between said electrode and the other two electrodes.

(Serial No. 68,259)

An affidavit executed by Harold D. Arnold is attached hereto overcoming the British patent 15,788 of 1914 as a reference so far as these claims are concerned. An affidavit executed by Russell F. Trimble is also attached, verifying the statements made by Arnold in his affidavit.

Allowance of the application, as now amended, is respectfully requested.

Respectfully,

HAROLD DeFOREST ARNOLD,

By J. H. Robinson
Attorney

463 West Street,
New York, August 23, 1917.

RIW/JT
F.P.50

MAIL ROOM

UNITED STATES PATENT OFFICE

In re application of
Harold D. Arnold,
Serial No. 62,269,
Filed November 18, 1915

Manufacture of Vacuum Tube Devices

AFFIDAVIT

County of New York,)
) ss.
State of New York.)

HAROLD D. ARNOLD being duly sworn, deposes and says:

That he is of legal age and a citizen of the United States; that he is the applicant named in the application, above identified; that he made the invention set forth in the claims in said application prior to October 1, 1915; and that the invention had been used extensively by himself and those assisting him in the laboratories of the Western Electric Company, Incorporated, prior to said date of October 1, 1915; that he does not know and does not believe that the invention has been in public use in this country for more than two years prior to his application, and that the said invention has never been abandoned.

Harold D. Arnold

Subscribed and sworn to before me this 23rd day of April, 1917.

Robert E. Millican
Notary Public

FIW:JO

UNITED STATES PATENT OFFICE

In re application of
Harold D. Arnold
Serial No. 62,259
Filed November 18, 1915

Manufacture of Vacuum Tube Devices

AFFIDAVIT

State of New York)
) ss.
County of New York)

RUSSELL FAY TRIMBLE, being duly sworn, deposes and says:

That he is of legal age and a citizen of the United States; that he has been in the employ of the Western Electric Company, Incorporated, since and prior to January 1913; that since said date of January 1913, he has been in charge of a large part of the work relating to the evacuation of vacuum tube devices; that prior to October 1, 1915 it was a usual and common expedient in the laboratories of the Western Electric Company, when evacuating such devices, to have one electrode (in the form of a filament) heated to incandescence and to have a second electrode connected to said first electrode by means of a source of potential, the second electrode being connected to the positive terminal of the source, whereby an electron discharge was caused to flow from said filament to said second electrode. The purpose of this was to bombard and heat the second electrode in such a manner and to such an extent as to cause it to give off occluded gases. This method of evacuating vacuum tubes was followed by myself and my assistants,

and was done at the suggestion and under the instructions of Harold D Arnold, under whose direction I was working.

W Gray Sutton

Subscribed and sworn to before me this 23rd day of April, 1917.

Robert E Mellon
Notary Public

PIW-PJ
JT

APPROVED.
Under Order 2225.
T A Hostetler
Lieut. Col. Sig. R.C.
May 28-1917

76

Dev. 16 Room 109 — 2-200 — Paper No. 4

Address only "The Commissioner of Patents, Washington, D. C." and not to individuals by name.

F.H.

All communications respecting this application should give the serial number, date of filing, title of invention, and name of the applicant.

DEPARTMENT OF THE INTERIOR

UNITED STATES PATENT OFFICE

WASHINGTON June 6, 1917.

Mr. John G. Roberts,

465 West Street,

New York, N. Y.

Please find below a communication from the EXAMINER in charge of the application of

H. D. Arnold, S. No. 62,259, filed Nov. 16, 1915,

Manufacture of Vacuum Tube Devices.

Thomas Ewing
Commissioner of Patents.

This action is in response to amendment filed Apr. 24, 1917.

Claim 1 is rejected as not setting forth a method for producing a vacuum as the operation set out is insufficient to produce a vacuum. Further, the operation set out is a step described in the evacuating process described in patent No. 1,166,792, Emdek, of record. See page 4, lines 31 to 80 of the reference. This claim is accordingly rejected on patent No. 1,166,792, cited.

Claims 2 and 3 appear to be allowable.

H. C. Akinman
Examiner, Division XVI.

R.W.S.

Case 16

UNITED STATES PATENT OFFICE.

Division 16 Room 109

In re application of

Harold DeForest Arnold

Serial No. 62,259

Filed November 18, 1915

Subject.

Manufacture of Vacuum Tube Devices

THE COMMISSIONER OF PATENTS,
Washington, D. C.

Sir:

In reply to the Office action of June 6, 1917, please amend as follows:

Claim 1, line 2, cancel "consists in" and substitute --comprises performing the following steps during the process of evacuation, i. e.--; line 4, after "and" insert --simultaneously--.

Add the following claims:

--4. The method of producing a high vacuum in a thermionic discharge tube having a filamentary cathode which consists, during the process of evacuation, in passing an electric current through said cathode to heat the same independently of electron bombardment and in heating another electrode in said tube by a space current between said cathode and said electrode.

5. The method of producing a high vacuum in a thermionic discharge tube having a cathode and an auxiliary electrode which consists, during the process of evacuation, in passing an

FORM 36—30
COMMUNICATION TO PATENT OFFICE
3 NEEDED

(Serial No. 62,259)

electric current through said cathode to heat the same independently of electron bombardment and in heating said auxiliary electrode by bombardment from said cathode.--

R E M A R K S

Claim 1 has been amended to define a method for producing a vacuum and this has been done in terms which differentiate from the references of record by specifying that one of the electrodes is heated to incandescence and that simultaneously an electron discharge is established between said electrode and a second electrode.

It is thought that claims 4 and 5 should be allowed as the patent to Snook does not disclose a cathode which is heated independently of bombardment by an electric current passing therethrough. In applicant's case two or more electrodes may be kept hot, while the tube is pumped out, one being heated by bombardment and the other being heated independently of bombardment. This individual control of the heating of the electrodes appears novel with applicant and it is submitted that the claims 4 and 5 should be allowed.

Reconsideration and allowance are therefore respectfully requested.

Respectfully,

HAROLD DeFOREST ARNOLD,

By J. F. Roberts
Attorney

463 West Street,

New York, March 1st 1918.

WEB:T

Div. 16 Room 118 ABS. 1-282 Paper No. 6

Address only "The Commissioner of Patents, Washington, D. C." and not any official by name.

All communications respecting this application should give the serial number, date of filing, title of invention, and name of the applicant.

DEPARTMENT OF THE INTERIOR

UNITED STATES PATENT OFFICE

WASHINGTON June 18, 1918.

John G. Roberts, Esq.,

465 West 23d.,

New York, N.Y.

Please find below a communication from the EXAMINER in charge of the application of

Harold D. Arnold, Ser. No. 63,859, filed Nov. 18, 1915,

Manufacture of Vacuum Tube Devices.

James T. Newton

Commissioner of Patents.

1-282

This action is in response to amendment filed Mar. 15, 1918.

Claims 1, 4 and 5 are rejected on any one of the following references:-

COOLIDGE, 1,205,495, Oct. 31, 1916, (280-30);
" 1,211,091, Jan. 2, 1917, "
" 1,211,092, Jan. 2, 1917, "

Attention is called especially to: page 3, lines 81 to 86, of patent 1,205,495; to page 2, lines 26 to 30, of patent 1,211,091, and to page 2, lines 4 to 15, of patent 1,211,092, all cited above.

Claims 2 and 3 appear allowable.

If, by the date of applicant's next action, this application will have been pending three years or more, it will come within the Commissioner's order respecting delayed applications, and the amendment cannot be entered without the special approval mentioned therein. For these reasons, applicant is urged to place the application in condition for final action.

JLO

Examiner, Division 16.

80

Case 15

UNITED STATES PATENT OFFICE

In re application of

HAROLD D. ARNOLD

Serial No. 62,259

Filed Nov. 18, 1915

Subject: Manufacture of Vacuum Tube Devices

16

THE COMMISSIONER OF PATENTS,

Washington, D. C.

Sir:

Please note that the address of DeWitt C. Tanner and myself, as attorneys of record in the above application, will be, until further notice, 920 Broadway, New York, N. Y.

Respectfully,

J. S. ROBERTS

Date: September 9, 1915.

920 Broadway, New York, N. Y.

Case 16 81

UNITED STATES PATENT OFFICE.

Division 16 Room 112

In re application of

Harold DeForest Arnold

Serial No. 62,259

Filed November 18, 1915

Subject.

Manufacture of Vacuum Tube Devices

THE COMMISSIONER OF PATENTS,
Washington, D. C.

Sir:

In reply to the Office action of June 18, 1918, please amend the above entitled application by cancelling all the claims and substituting therefor the following:-

1. The method of producing a high vacuum in a thermionic discharge tube containing three electrodes, which comprises heating one of said electrodes and establishing an electron discharge between said heated electrode and a second one of said electrodes, whereby said second electrode is heated during the process of evacuation, and in assisting the passage of said discharge by means of a potential difference applied between the source of said discharge and the third electrode.

2. The method of producing a high vacuum in a thermionic discharge tube containing three electrodes, which comprises heating one of said electrodes to cause it to emit

electrons, in establishing an electron discharge between said heated electrode and the other two electrodes during the process of evacuation, whereby said two electrodes are heated by bombardment and their occluded gases are driven off.

3. The method of evacuating a vacuum tube having cathode, anode and grid electrodes, which comprises energizing said cathode to cause it to emit electrons, in establishing an electron discharge between said cathode and said other electrodes during the evacuation, and in maintaining said grid at a potential different from that of said cathode during said discharge.

4. The method of evacuating a vacuum tube having cathode, anode and grid electrodes, which comprises energizing said cathode to cause it to emit electrons, and in maintaining said grid and anode at a positive potential with respect to that of said cathode during evacuation.

REMARKS

By reason of the amendments to allowed claims 2 and 5, these have been rewritten, and in their present form, as claims 1 and 2, differ but slightly from the form in which they were allowed. The principal difference is that the limitation as to heating one of the electrodes to incandescence has been

(Serial No. 62,259)

broadened to state that the electrode is heated, without regard as to whether this is to the point of incandescence or not. It is thought that these claims will still be allowable.

Claims 3 and 4, added by this amendment, are specific to the type of tubes which is to be evacuated, and to the potentials which are applied between the electrodes during evacuation.

Claim 4 is more specific than any of the others in that it recites that the grid is maintained at a potential which is positive with respect to the cathode during the evacuation.

This case is now believed to be in condition for allowance.

Respectfully,

HAROLD DeFOREST ARNOLD,

By H. E. Roberts
Attorney

920 Broadway,
New York, November 17. 1918.

WEB:T -3-

84

ADDRESS ONLY THE COMMISSIONER OF PATENTS, WASHINGTON, D. C.

LBG 2—181

Serial No. 62259

DEPARTMENT OF THE INTERIOR

UNITED STATES PATENT OFFICE

WASHINGTON, Dec. 16, 1918

Harold D. Arnold, Assor. by mesne assigts. to Western Electric Company, Incorporated, a corporation of New York

Sir: Your APPLICATION for a patent for an IMPROVEMENT in

Manufacture of Vacuum Tube Devices

filed Nov. 18, 1915, has been examined and ALLOWED.

The final fee, TWENTY DOLLARS, must be paid not later than SIX MONTHS from the date of this present notice of allowance. If the final fee be not paid within that period, the patent on this application will be withheld, unless renewed with an additional fee of $15, under the provisions of Section 4897, Revised Statutes.

The office delivers patents upon the day of their date, and on which their term begins to run. The printing, photolithographing, and engrossing of the several patent parts, preparatory to final signing and sealing, will require about four weeks, and such work will not be undertaken until after payment of the necessary fee.

When you send the final fee you will also send, DISTINCTLY AND PLAINLY WRITTEN, the name of the INVENTOR, TITLE OF INVENTION, AND SERIAL NUMBER AS ABOVE GIVEN, DATE OF ALLOWANCE (which is the date of this circular), DATE OF FILING, and, if assigned, the NAMES OF THE ASSIGNEES.

If you desire to have the patent issue to ASSIGNEES, an assignment containing a REQUEST to that effect, together with the FEE for recording the same, must be filed in this office on or before the date of payment of final fee.

After issue of the patent uncertified copies of the drawings and specifications may be purchased at the price of FIVE CENTS EACH. The money should accompany the order. Postage stamps will not be received.

Final fees will NOT be received from other than the applicant, his assignee or attorney, or a party in interest as shown by the records of the Patent Office.

Respectfully,

James T. Newton

Commissioner of Patents.

Mr. John G. Roberts,

1920 Broadway,

New York, N. Y.

IN REMITTING THE FINAL FEE GIVE THE SERIAL NUMBER AT THE HEAD OF THIS NOTICE.

UNCERTIFIED CHECKS WILL NOT BE ACCEPTED.

85

Case 15

1/20

ck'd

UNITED STATES PATENT OFFICE.

In re application of

Harold D. Arnold

Serial No. 62,269

Filed November 18, 1915

Allowed December 16, 1918

Subject: Vacuum Tube Devices

THE COMMISSIONER OF PATENTS,
Washington, D. C.

Sir:

The enclosed check for $20.00 is in payment of the final Government fee on the above named application.

Respectfully,

J. G. ROBERTS,
Attorney for Applicant.

Date: February 13, 1919
920 Broadway,
~~463 West Street~~
New York, N. Y.

88

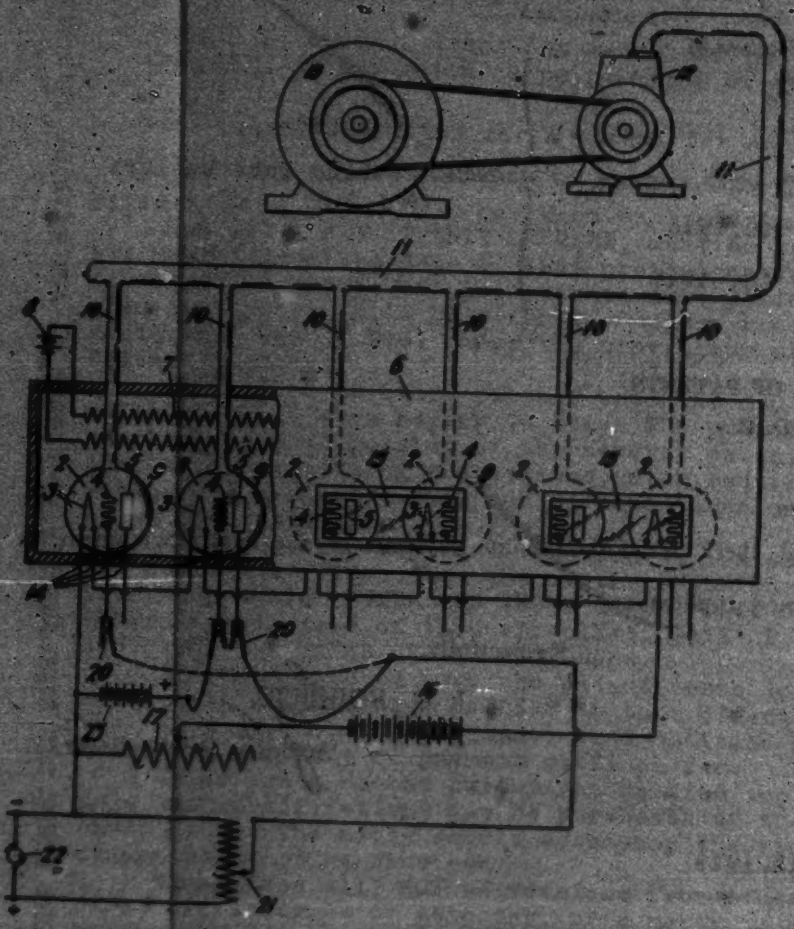
H. D. ARNOLD.

MANUFACTURE OF VACUUM TUBE DEVICES.

APPLICATION FILED DEC. 16, 1915.

1,297,809.

Patented Mar. 18, 1919.



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Inventor:
Harold D. Arnold
by A. C. Stannard Att'y.

UNITED STATES PATENT OFFICE.

HAROLD D. ARNOLD, OF EAST ORANGE, NEW JERSEY, ASSIGNOR, BY MESNE ASSIGNMENTS, TO WESTERN ELECTRIC COMPANY, INCORPORATED, A CORPORATION OF NEW YORK.

MANUFACTURE OF VACUUM-TUBE DEVICES.

1,297,309. Specification of Letters Patent. Patented Mar. 18, 1919.

Application filed November 18, 1915. Serial No. 62,262.

To all whom it may concern:

Be it known that I, HAROLD DE FOREST ARNOLD, a citizen of the United States, residing at East Orange, in the county of Essex and State of New Jersey, have invented certain new and useful Improvements in the Manufacture of Vacuum-Tube Devices, of which the following is a full, clear, concise, and exact description.

This invention relates to the manufacture of vacuum tube devices, and more particularly it relates to a method of exhausting air and other gases and vapors from the glass bulbs or containers which inclose the electrode elements of thermionic repeaters, such as audions, and similar devices in which extremely high vacua are desired.

Its objects are an effectively complete elimination of the gases occluded by the walls of the containing vessel, and by the electrode elements and other metallic surfaces inclosed therein, a removal of such gases or any other gases from the containing vessel, and a resulting product characterized by stability and uniformity of operation.

To these ends this invention provides for the attachment of the vessel to be exhausted to any suitable vacuum pump and for the application of heat to the exterior of such vessel during the process of evacuation. It further provides for the heating of one or more of the inclosed electrodes by the passage of an electric current therethrough, and for the production in said vessel of an electron discharge which may be made to bombard and heat another electrode through the application of a suitable potential difference between the said electrode and the source of said discharge.

A more complete understanding of the method of this invention will be obtained by consideration of the attached drawing, which illustrates an apparatus arrangement suitable for producing the high vacua desired in thermionic devices of the audion type. It will, of course, be appreciated that the method herein disclosed is equally applicable to the production of high vacua in any device having an electrode or electrodes capable of producing an electron discharge.

In the drawing, a plurality of thermionic repeater elements 2, each having the customary filamentary cathode 3, grid 4 and anode 5, are inclosed in an oven 6 which may be electrically heated by a resistance element 7 connected to a suitable source of current 8. The glass containing-vessels 9 of the elements 2 have tubular extensions 10 connected to a main tube 11 leading to an exhaust apparatus 12, such, for example, as a Gaede molecular pump, connected to a source of motive power 13. The terminals of the electrode elements 3, 4 and 5 are brought out through suitable apertures 14 in one of the walls of the oven 6, so as to be readily available for test purposes and for the application of any desired electromotive force. A suitable number of windows 15 are provided in the front of the oven 6 so that the appearance of the tubes 2 being exhausted may be observed during the process. The filaments 3 are connected in series with a source of current 16 and a variable resistance 17. The process of exhausting the vessels 9 is as follows: The pump 12 is started and the temperature of the oven 6 is gradually raised until it has reached approximately 350° C. The purpose of this heating is to drive out the gases occluded by the walls of the vessel 9. After the temperature of the oven has risen to about 250° C., the filaments 3 are brought to incandescence by current supplied from the source 16, which current is raised to a value approximately 10% greater than the current normally to be used in the operation of the completed device. A potential difference is thereupon successively applied to the terminals of the electrodes 4 and 5 by means of a test clip 20 connected through the potentiometer 21 to a direct current source 22 of about 220 volts output. The filament 3 being connected to the negative terminal of the source 22 as shown, and the test clip 20 being connected to the positive terminal of the source 22, there will result an electron discharge from the cathode 3 to the electrode 4 or 5, to which the test clip 20 is temporarily connected. This potential difference is made sufficiently high, through adjustment of the potentiometer 21, to cause an electron discharge of sufficient volume to heat the electrode, to which the test clip 20 is attached, even to incandescence, which heating is effective to drive out any gases which may be occluded by said electrode.

The electron discharge, which passes from the cathode 3 to either electrode 4 or 5, when

potential difference is established therebetween, partially ionizes whatever gas may be in its path. When gas in sufficient quantity is thus ionized, there will result a blue glow in part or all of the vessel 9, which may readily be observed through one of the windows 15. The intensity of this blue glow depends upon the amount of gas present and upon the current and potential difference impressed between the cathode 3 and electrode 5. For a given current and potential difference therefore, this blue glow will gradually become fainter as the gas within the vessel becomes more attenuated, until the glow finally disappears.

A visible indication of the sufficiency of evacuation is therefore available, and, for example in exhausting the bulbs of thermionic repeaters, such as are employed in telephone work, it has been found that a sufficiently high vacuum has been obtained if the blue glow no longer appears, when approximately 175 volts potential difference is impressed between the cathode 3 and the anode 5. When this point has been reached, the tubes are allowed to cool gradually and are sealed off of the pump 12 and given an aging run, which consists in applying the normal heating current to the filaments 3 and impressing the customary operating potential difference between the cathode 3 and anode 5. It has been found that after an aging run of from fifteen to twenty hours duration, for example, the repeaters have reached a stable condition and may be relied upon to give constant and uniform results.

In case the thermionic device to be exhausted is equipped with a grid 4 of very fine mesh, as in the case of a repeater designed for voltage amplification, it may be difficult to obtain a current to the electrode 5 sufficient to heat it properly. In such an event, it has been found desirable to apply an additional positive potential from a source 23, for example of perhaps 60 volts output, to the grid electrode 4 at the same time that the positive potential from source 20 is being applied to the anode 5. This increases the flow of electrons to the anode 5, and as some current will also flow between the filament 3 and grid 4, the voltages may be adjusted so as to heat both electrodes 4 and 5 at the same time.

With some tubes the early part of the process may be accelerated by applying to both the grid electrode 4 and the anode 5 the same large potential as that which later in the process is applied to the anode only.

What is claimed is:

1. The method of producing a high vacuum in a thermionic discharge tube containing three electrodes, which comprises heating one of said electrodes and establishing an electron discharge between said heated electrode and a second one of said electrodes, whereby said second electrode is heated during the process of evacuation, and in assisting the passage of said discharge by means of a potential difference applied between the source of said discharge and the third electrode.

2. The method of producing a high vacuum in a thermionic discharge tube containing three electrodes, which comprises heating one of said electrodes to cause it to emit electrons, in establishing an electron discharge between said heated electrode and the other two electrodes during the process of evacuation, whereby said two electrodes are heated by bombardment and their occluded gases are driven off.

3. The method of evacuating a vacuum tube having cathode, anode and grid electrodes, which comprises energizing said cathode to cause it to emit electrons, in establishing an electron discharge between said cathode and said other electrodes during the evacuation, and in maintaining said grid at a potential different from that of said cathode during said discharge.

4. The method of evacuating a vacuum tube having cathode, anode and grid electrodes, which comprises energizing said cathode to cause it to emit electrons, and in maintaining said grid and anode at a positive potential with respect to that of said cathode during evacuation.

In witness whereof, I hereunto subscribe my name this fifteenth day of November, A. D. 1915.

HAROLD D. ARNOLD.

2-41

1915

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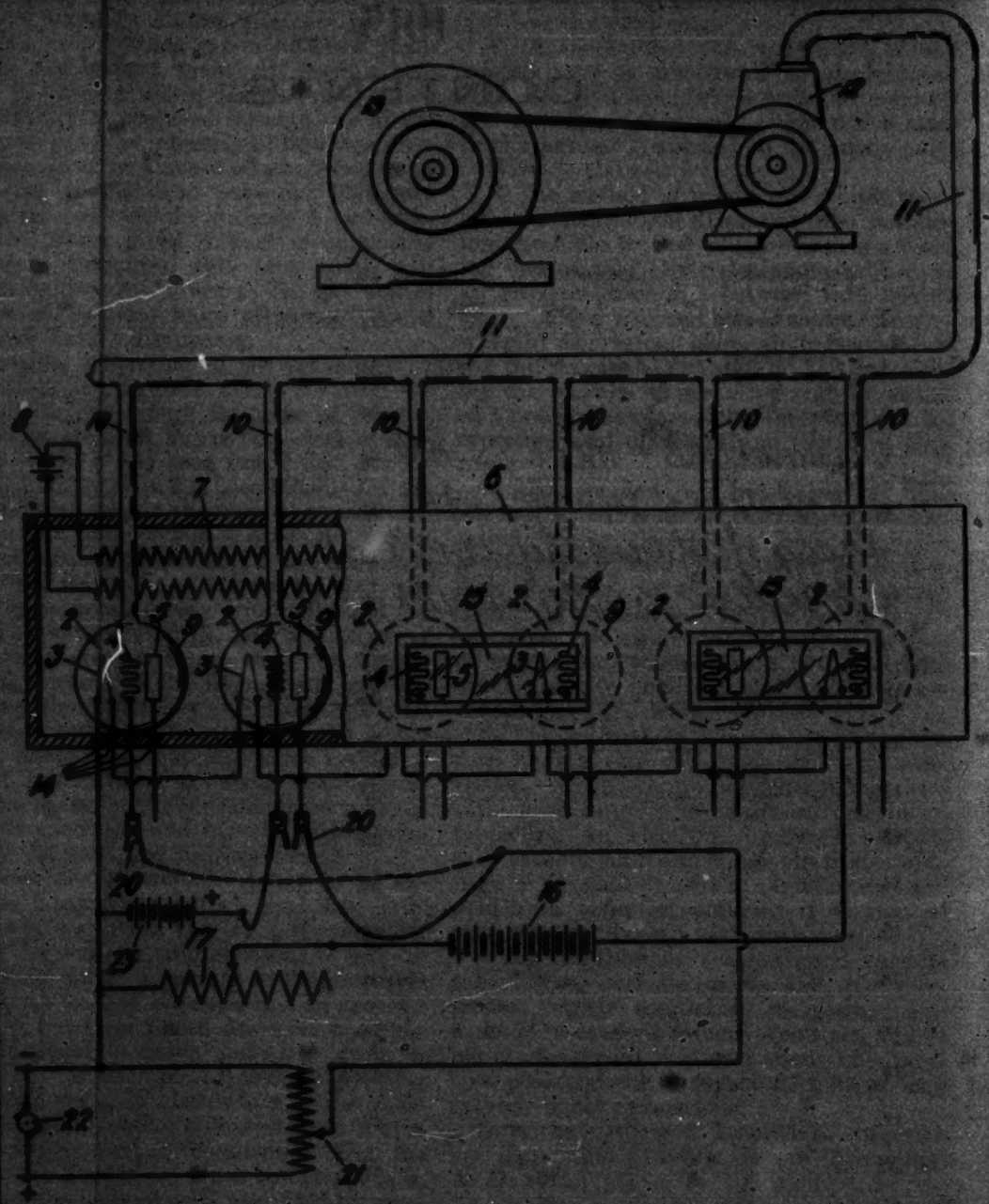
H. D. ARNOLD.

MANUFACTURE OF VACUUM TUBE DEVICES.

APPLICATION FILED NOV. 18, 1915.

1,297,309. Patented Mar. 18, 1919.



Inventor:
Harold D. Arnold
by A. C. Stanner. Atty.

Mar 1-2 1918

PLAINTIFF'S EXHIBIT No. 171.
White Note Book No. 452.

20

Mon. Feb. 10 '13

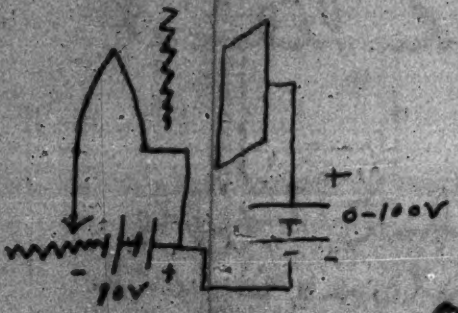
Cleaned up a quantity of mercury for Dr. Story. Air blown thru it for a numbr of hours.

Have decided that trouble with vacuum system is with gage column so will take it down and have a new fitting put in and give whole a good cleaning.

Spent afternoon in conversation with Dr Langmuir in regard to some experiments I am to try with the De Forest audion.

Thurs. Feb. 13 '13

assembled apparatus and made some tests on the De Forest Audion.



Mr. Kaye and Orange calibrated the audion filament. Current temp. relation given on C.S.W. 20.

Fri Feb 14 13
to
Tues Feb 25 '13

away from lab on account illness.

Small rotary converter for vacuum gage has been fitted with steel rings and metite brushes. It runs much smoother and should last a long while.

Thurs Mar 13 to Sat Mar 15

Completed vacuum system and evacuated an all tungsten audion. Treatment given on R.S.-W.77

Filament color matched by Orange and Mackay:

at 1.025 amps and 4.05 V Temp was 2452°C Then from curves of ideal filament current-temperature curve drawn as on C.S.W.25.

lines at very low plate voltages and high + grid voltages the curves are distorted due to fact that grid current is large in comparison with plate current.

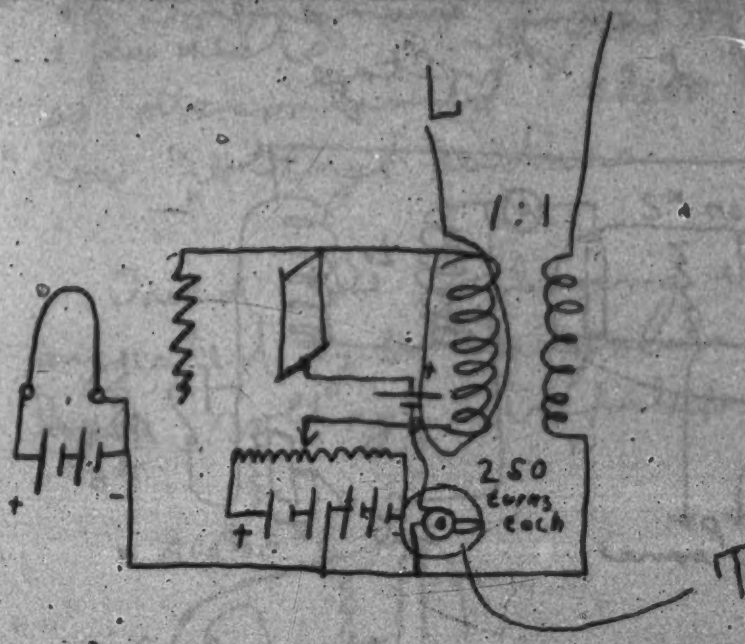
In both these sets of tests filament kept at 1.05 amps 2430°C which is about saturation on all voltages up to about 200.

From data of these two tests draw curves showing relation between grid E.M.F. and plate E.M.F. these are straight lines as long as plate current is large in comparison to grid current. These curves drawn for different currents.

In commencing tests for the day it was necessary to run filaments for quite a time to get results consistants with previous days results. At first results were 5 to 10% high.

Tried to use # 2 as a wireless receiver using a buzzer for sender. Could get no results.

35

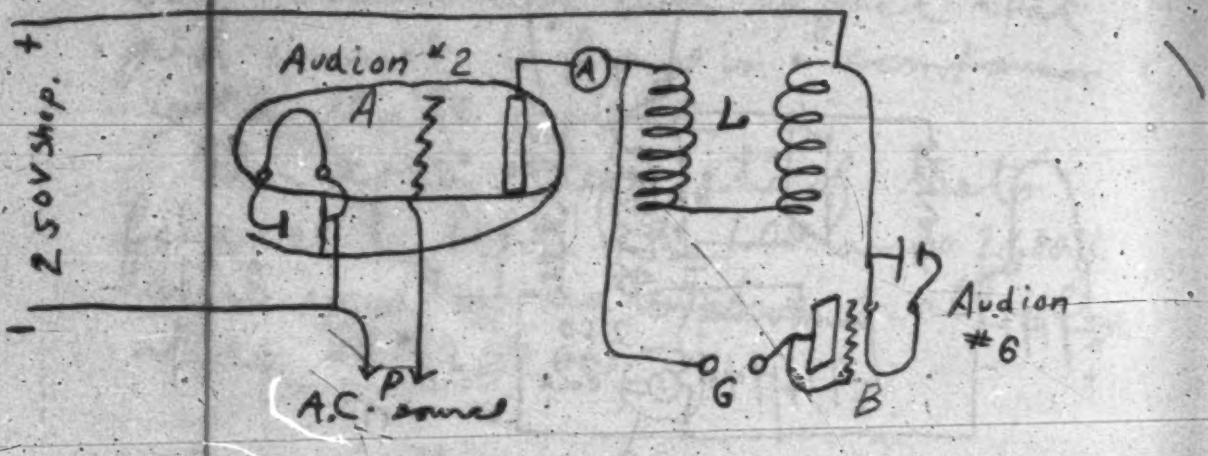


When filament is at about 1 amp a low pitch sort of rattling is heard as filament temperature is raised this raises in pitch till at about 1.3 amps it is a sort of squeal. Magnetic lines of force have the same pitch raising effect when ~~them~~ parallel to filament.

There is also a decided microphone effect.

Dr Jorgensen suggested a D.C. transformer.

4/1/13 Used the following arrangement to step up d.c. voltage.

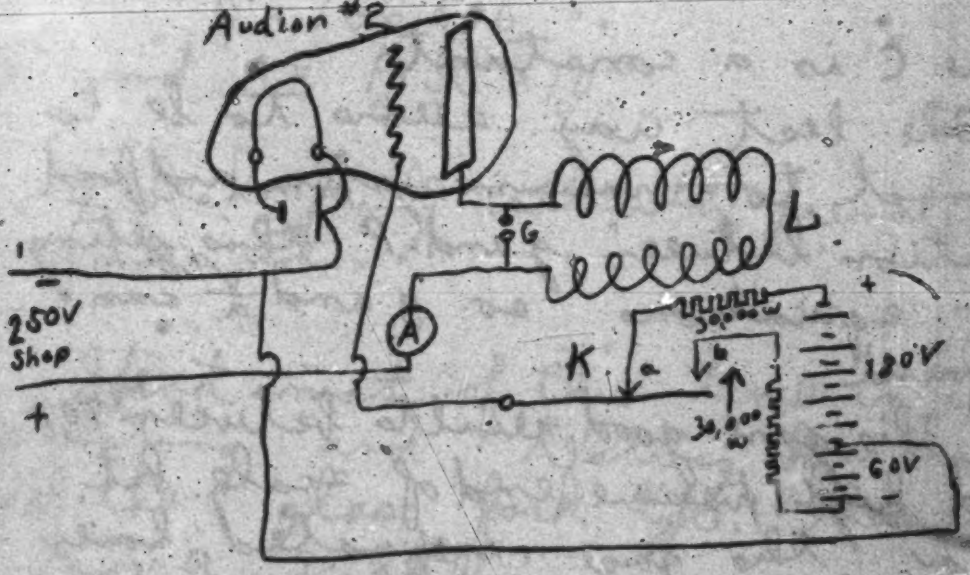


L is an inductance consisting of the primaries of two 200 watt 6600/100 V Pot. transformers connected in series. Various A.C. sources were tried 40 ~ shop at 25 V and a special 100 ~ alternator at about 30 V

The idea being to charge up the inductance while the grid of #2 is + the E.C. doing this then in next part of cycle when grid is - the E.C. is suddenly shut off, thus allowing the coil L to discharge across gap G audion #6 being used as a rectifier. The higher voltage thus obtained would just about jump the smallest gap we could arrange as potential was

probably about 350-400 Volt, after a few tests blue glow began to appear so discontinued these tests on these low voltage audions.

Tried the following arrangement suggested by Dr Langmuir to get single high voltage impulses



The key K being used to change the sign of the grid potential very suddenly. Shunt of 0.3 m m coal fell [illegible] from the 250 V shop.

About 25 mil-amps was passed thru L. when grid was +

The high resistances were used

Calibrated another gage of the Moore type for Mrs Perkins. Tried it by volume and diam. measurement but unsatisfactory.

We know that relation should approximately be

$$C + g = \frac{PV}{ag} \quad \text{see fig 40}$$

where C is a constant

The best way seems to be to connect to a vacuum system and find relation between g and P, thus getting two equations so g and $\frac{V}{a}$ can be found

This gave good results between 70 p and high pressure end of scale but below this gage indicated lower pressure than equation ~~gave~~ gave.

Wired up a 10 K.V.A. 40,000 V transformer with regulator (induction) and reactance in secondary, to be used on high voltage and/or relays ect.

57

April 28 to May 10

Made some tests on audion #2 to get total currents obtained from filament. See RSW 79.

Tried to find Q and A for this filament

It is a 2.7 mil, 14.05 mm long and $\therefore = 3.03\ mm^2$

$Q = 166{,}500$

and $A = 19.55 \times 10^{15}$

Q checks fairly well with Irenias results A does not.

Spent most of this time in constructing and testing four audions of the glass fork type. These are nos 6, 7, 8, 9.

Construction data given on pgs 48, 54, 55.

Principal construction troubles were:

Winding of fine grid, this overcome by practice and more careful handling of wire. Breaking of fork due

$L = .0000572$ Henrys

For this coil the field at any point along the axis as relative to the field in plane of coil is given on C.S.W. 45 Here inverse values of relative field strength are plotted against distance along axis from plane of coil. For instance at 100 cm along axis field is only $\frac{1}{133}$ of its value at center of coil

Ifer tested out Mr. Alexanderson theory of geometrical tuning using two audions in series, the results of this test are described in a report. Particulars given on RSW 100-103

Evidently this feature is little effected by geometrical construction

Dr. Langmuir thinks this is due to fact that electrons leave filament at different velocities according to Maxwells distribution law / so that a certain E.M.F range is necessary to cover this range of velocities /

Tried cliffing audion #2 into a solenoid, capable of giving quite a powerful field.

Under certain conditions noted RSW98 the grid Eg vs E.C. curve took on form shown on CSW50. Having a sharp discontinuity, in all cases the magnetic lines parallel to the filament caused decrease in E.C. and if field was strong enough entire stoppage of it.

This fact latter may be of great value as the sensitiveness must be extremely great, which was tested out as follows.

Mon. May 26 '13

Worked on effect of high frequency geometrical timing with audions.

Tues May 27 '13

Tested out all other available audions inside of a solenoid but #2 was the only one which gave the discontinuity effect. I suspect the effect is due to positive ionization because

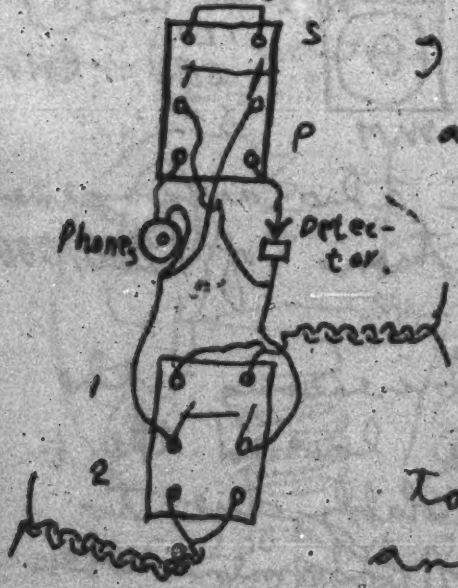
1st after operating a while there is a lag between grid E.M.F critical values depending on whether it is being raised or lowered last the point.

2nd For no apparent reason the effect will sometimes mysteriously disappear and later just as mysteriously appear again.

3rd This audion #2 is the only one which shows effect and is the only one we have which has shown this

Mr Brooks is starting a wireless receiving station in Bldg 4 and I have given him one of our audions to use. (#8) So far he has not used it to receive messages although it responds to the buzzer as well as a galena detector he is using.

Rogers has rigged up a silicon detector in connection with a couple of DP DT switches



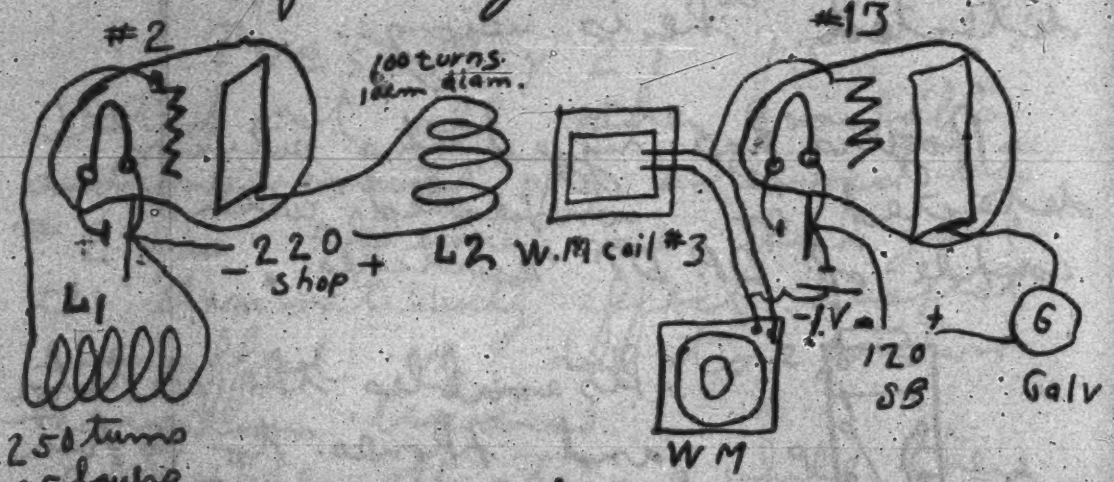
This enables the detector and phones to be put in series or parallel and to either of two circuits.

The detector seems to work fairly consistently

With this arrangement tested out audion # 2 as a multiplier of oscillations.

Duehman has found that when an audiotron is placed in good circuit oscillations are set up which are amplified in the plate circuit, tried to detect these oscillations on one of our small audions #2.

Used following connections



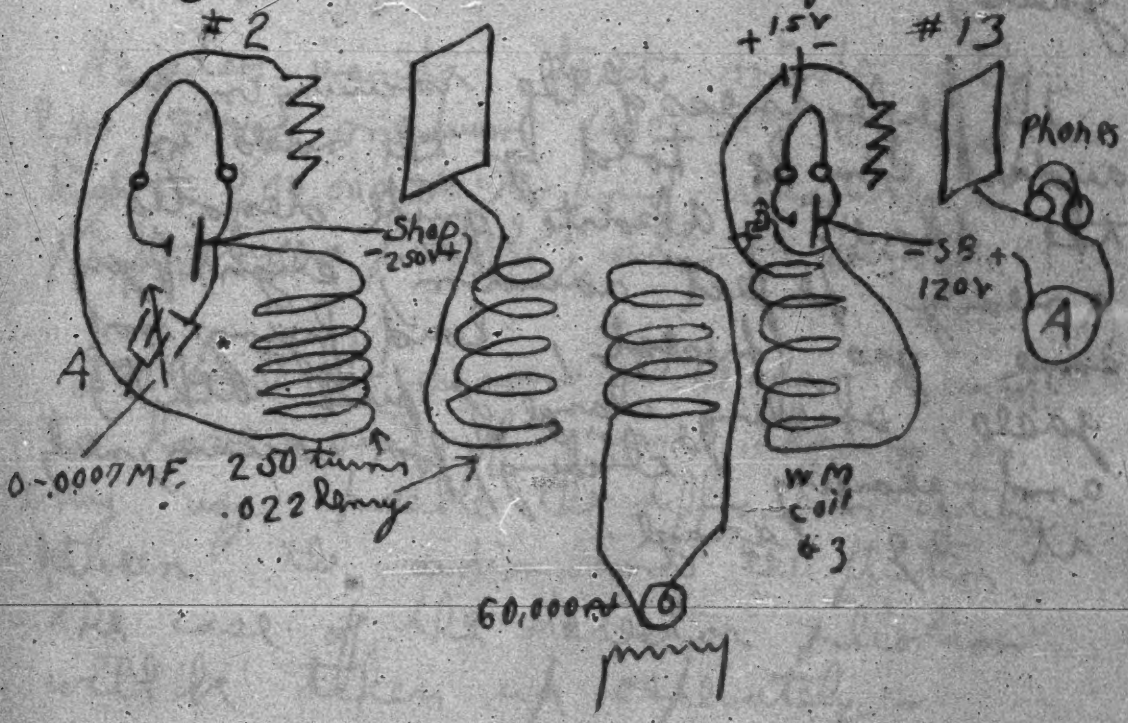
Found that this arrangement gave oscillations of 126,000 cycles per second.

also found that increasing the filament temperature lowered the frequency. This is probably due to change in portion of filament when heated causing change in capacity of audion

Increase of plate voltage

second and will neutralize the result being zero only 1000th of a second so that the effect in the phone will that of a 1000 cycle current which is easily heard. This arrangement choked improve the sensitiveness of the detector for here the whole variation is made use of and not just the assymetry.

For tests the following arrangement was used on the first trial



easily according to A.B.C. allison:

add a solution of Sodium Hyposulphite to one of cotter sulphate in the cold add HCl, filter and wash first then wash first in grain alcohol, result is Cu_2H.

The same difficulty however will be experienced in freeing from contained gases,

The perfectness of the vacuum in an audion can be told by the rods in the stand. absolute quite denotes a nearly perfect vacuum, slight fuzzy some gas present, loud fuzzy much gases, sticking charge of pitch dth E.g and clapping, clicking, poor vacuum, nearly at b.g. stage.

252

Dec 22 to Dec 29 1913

Had a talk with Dr Langmuir, he wants some pieces of apparatus made up to demonstrate Audions
1st a detector outfit
2nd an amplifier "
3rd a telephone relay.

Several amplifiers should be made up so that tuning in geometrical progression may be illustrated.

He also wants test made with low (60~) medium 1000-2000~ and high 200,000~ to find relations and applications possible, with & tuning.

For patent reasons it is also desired to have a series of curves showing in every way possible the different in action between the audion and the Audion, the case of the detector Audion will be taken up seperately.

PLAINTIFF'S EXHIBIT No. 172.
White Test Records.
(Card and 6 Sheets.)

#2 OK 4/10/43

Glass fork type
2.7 mil fil 14.05 cm
1.5 mil hard wound grid
5 mil zigzag plate.
2 mm from grid
70 mil. grid fork.
Grid lead thru stem

Audion #2.

2.7 mil W filament Do not run above 1.2 Amps.

°C Abs.	Amps
2000	.71
2100	.775
2200	.845
2300	.917
2400	.99
2480	1.05
2600	1.14

filament takes about 4 V at 2450°

Plate and grid insulation good to 250 V.

Conditions become constant after running fil 5 min at 2500°C.

Tungsten Wire Audion. RSW 77

Date	Time	Press μ	Temp	
3/13/13	4.00			Started old exhaust
	5.15	.2	Room	
3/14/13	8.00	1.7	Room	Started oven
	8.30	6.5	330	
	8.40	8.0	350	
	9.05	9.	350	turned on fourth.
				left pumping and at 350°. till 11.15
				got down to .2μ plate hot
	12.00	.10	room	
	1.30	.10	"	
				Sealed plate filament well
				and filament one sealed off at .05μ

Audion #2

RSW78

K=.0158

Date	lamp amps	Amp Lamp	°C Abs	Plate volts	Edison I meter	Edison I milamps	
3/17/13	.67	1942	30	.05	.00079		
	.78	2105		2.45	.0387		
	.82	2163		7.5	.1184		
	.96	2358		13.6	.215		
	.72	2017		.2	.00316		
	.75	2061		1.1	.0174		
	.81	2148		4.7	.0742		
	.88	1956	70	.05	.00079		
	.73	2036		.65	.01003		
	.76	2076		2.1	.0332		
	.78	2105		4.8	.0758		
	.8	2135		9.0	.142		
	.81	2148		11.2	.177		
	.82	2163		12.6	.199		
	.83	2178		16.4	.259		
	.92	2304	30	10.6	.1674		
	1.015	2433	"	16.4	.259		
Vgrid	<1.25	<2725	30	0	0		
"	.72	2116	70	.1	.00158		
"	.85	2206	70	.55	.00869		
"	1.0	2412	"	1.1	.0174		
"	1.1	2545	"	1.6	.0253		

115 V grid-filament

Amp Lamp	°C Abs	Plate volts	Edison I meter	Edison I milamps	
.8	2135	115 to 120	.28	.3	
.9	2275		3.	.321	
.1.	2412		13.5	14.45	
.95	2345		6.5	6.95	
1.05	2480		26.0	26.	K=1
.85	2206		.5	.535	
>1.05	2500	4.8	.2	.214	K=1.07
		3.3	.47	.503	
		5.7	9.5	1.02	
		7.5	1.6	1.714	
		13.2	3.2	3.425	
		15.5	4.1	4.39	
		21.0	6.6	7.06	
		27.5	10.1	10.8	
		33.5	14.6	15.6	
		35.3	16.2	17.35	
		40	22.2	23.2	K=1
		50	31.	31.	
		75	35	35	
		61	33	33	Grid

Audion #2 RSW 79

Date	Lamp Amps	°C Abs	Plate volts	Edison Meter	Current Milamps	Grid volts	Grid meter	I milliAmp
3/19/13	1.051	2480	115	.9	.963	± 0	-.25	.00395
				1.37	1.467	+1.5	-2.3	-.0363
				1.9	2.02	+3.0	-6.7	.106
				2.45	2.61	+4.5	-11.8	-.1865
					K=1		K=1.07	
				3.6	3.6	+6.	-.2	-.214
				4.1	4.1	+7.	-.33	-.353
				4.8	4.8	+9.2	-.47	-.503
				6.	6.	+12.2	-.8	-.856
				7.	7.7	+15.2	-1.15	-1.23
				9.	9.	+18.3	-1.5	-1.605
				"	11.	11.	+22.5	-2.
				0	0	0	± 0	-2.25

K=.0158

Fil I	Fil °K	Total EC mm	I EC mm
.7	1990	1.1	.0174
.65	1912	.2	.00316
.75	2060	10.6	.1674
.8	2135	.6	.0642
.85	2206	1.9	2.033
.90	2275	5.0	5.35
.95	2345	10.5	11.23
1.0	2411	22	22

K=1.07

$\lambda = 1.405$

-.0355 with platefire

	115	.45	K=1	-1.5	0	0
		.13	1.3	-2.8	0	0
		2.5	K=.0158 .0395	-4.3	0	0
		.2	.00316	-5.8	0	0
		0	0	-6.8	0	0
1.05	50	5.	K=.0158 .079	-1.4	0	0
		.25	.00395	-2.9	0	0
		0	0	-4.3	0	0
		.27	K=1.07 .289	0.0	-.55	K=.0158 .0087
		.55	.589	+1.4	-3.45	.0545
		.9	.962	+3.0	-8.9	.141
		1.3	1.39	+4.5	-16.0	.253
		2.9	K=1. 2.9	+9.2	-.59	K=1.07 .031
		4.6	4.6	+13.7	-1.2	1.285
		6.2	6.2	+18.2	-2.13	2.28
		7.7	7.7	+22.5	-3.2	3.43
	75	1.25	K=1.07	+3	-7.9	K=.0158
		.8		+1.4	-2.8	
		.42		± 0	-.35	
				-1.4	0	

+ E.M.F. required to cause 0 E.C. to Plate

1.05 mill

Plate - Grid E.M.F.	Grid E.M.F.
11.0	6.2
8.0	5.0
6.0	4.2
4.0	3.3
2.0	2.7
.83	2.00
0	1.7

~~On Different Audion~~

0 2.25

On Same Plate

0 3.25

See RSW 82

Audion #2

R.S. W80

Date	Edison Meter	I Milliamps	Grid Volts	
2480	1.48	1.584	+14.75	132
1.05A	1.31	1.603	+11.55	126
10 Volts	1.09	1.167	+9.00	110
on Plate	.81	.866	+6.	91
	.42	.449	+3.	59
	15.9	.251	+1.5	40
	5.0	.079	0	16
	.9	.0623	-1.00	6
	.0	0	-2.00	0
	.25	.00395	-1.5	
	1.91	2.045	+22.5	165
	1.71	1.83	+18.1	150
2.35V	2.32	2.48	0	187
	14.00	15.0	+22.5	615
	11.8	12.63	+19.5	550
	10.1	10.8	+16.5	495
	8.45	9.04	+13.5	440
	7.1	7.6	+10.15.	390
	5.6	6.0	+7.3	335
	4.2	4.49	+4.35	275
	3.0	3.21	+1.45	220
	1.93	2.065	-1.0	164
	1.53	1.64	-2.0	140
	1.15	1.23	-3.0	113
	.56	.60	-5.0	52 71
	11.7	.185	-7.0	32
	2.45	.0387	-9.0	11.4
	.15	.00237	-11.8	
	.0	.000	-13.25	

Audion #2 RSW81

Date	E–C		Grid I		Total Grid Current	+ Grid EMF.
3/20/13	Meter	M.I.A. Ra. 37	Meter	M.I.A. Ra. 458	M.I.A.	Volts
	1.39		14.3			23.8
fil. at .85A	1.31		12.4			19.5
110–120 V ac	1.29		10.6			15.0
	1.30		9.1			10.5
	1.31		6.6			5.9
NG	1.07		2.9			3.0
115 V mot	1.31		7.4			6.9
going dat	.81		.9			1.4
	.53		0			0

used 2.0
.75 Amp fil

RSW 98

8/22/13

Audion 9-B at 625A

E_A	E_g	I_m	I_T
32	-3.5	12.5	.1975
	4	9.6	.152
	4.5	7.0	.1105
	5.	4.9	.0774
	5.5	3.7	.0585
	6.	2.6	.0411
	6.5	1.95	.0308
	7.	1.45	.0229
	7.5	1.1	.01774
	8.	.9	.0142
	9.	.65	.0103
	10	.4	.0063
	11	.25	.00395
	12	.12	.00189
	15	.000	.000

.0152

5/23/13

Audion #2 at 1.013 = 2430K

E_A	E_g	I_m	I_T
40	-3	.3	.00474
	-3.5	.1	.00158
	-5.5	0	0
	-2.5	.8	.0126
	-2	1.9	.03
	-1.5	3.7	.0584
	-1	6.3	.0994
	-.8	7.5	.1185
	-.6	8.8	.139
	-.4	10.3	.163
	-.2	12	.189
	-.1	12.8	.202
	0	13.9	.219
220	-6.5	14.8	.234
	-7	12.65	.200
	7.5	8.6	.136
	8.	7.9	.125
	8.5	6.25	.0985
	9.	4.7	.0741
	9.5	3.3	.0521

E_p	E_g	I_m	I_T
220	10	2.35	.0374
	10.5	1.7	.0268
	11.	1.15	.0182
	11.5	.75	.0119
	12.	.5	.0079
	12.5	.3	.00493
	13.	.2	.00316
	14.	.1	.00158
	15.5	0	00

.7 A Mag field

E_p	E_g	I_m	I_T
220	0	9.5	.15
	-.15	9.2	.145
	-.2	9.0	.142
	-.4	8.7	.137
	-.6	8.4	.133
	-.8	7.87	.124
	1.0	7.45	.1176
	1.2	7.0	.1105
	1.4	6.6	.104
	1.6	6.2	.098
	1.8	5.8	.0915
	2.	5.45	.086
	2.2	5.1	.0805
	2.3	5.0	.079
	2.4	4.95	.0781
	2.5	4.9	.0774
	2.6	5.1	.0805
	2.7	5.3	.0836
	2.8	5.25	.0829
	2.9	5.2	.0821
	3.	5.15	.0813
	3.15	4.7	.0742
	3.17	7.3	.115
	3.25	7.2	.1137
	3.5	6.8	.1074
	4.	6.25	.0986

E_p	E_g	I_m	I_T
220	-4.5	5.45	.086
	5.	4.8	.0758
	5.5	4.	.0631
	6.	3.2	.0505
	6.5	2.9	.0458
	7.5	2.0	.0316
	10.	.7	.01105
	12.5	.2	.00316
	20	.0	0

PLAINTIFF'S EXHIBIT No. 173.

Report on Relaying of High Frequency Currents by Means of Improved Audions.

W. C. WHITE

May 24, 1913. N. B. 452, pp. 61-64.

The two main objects in making these tests were, first, to determine if the improved audions would relay high frequency currents satisfactorily, and second, to get a working demonstration of geometrical tuning for wireless telegraphy as proposed by Mr. Alexanderson.

A standard 2 KVA high frequency alternator was used in connection with two of the improved audions.

A Marconi Wave Meter, consisting of a resonant circuit with variable condenser, was used to show that the high frequency current was correctly and sharply relayed.

Inductive coupling by means of air core coils was used to connect the different circuits.

A diagram of apparatus and connections is attached. Thruout the tests a constant current of 2.6 amps. was kept on coil D by field regulation of the alternator, so that a magnetic field of constant value was maintained about this coil.

The grid circuit of the first audion was tuned to 66,000 cycles, the audion relaying it to the grid circuit of the second audion, which by means of the wave meter was also tuned to 66,000 cycles.

The frequency was varied between 40,000 and 100,000 cycles, and a reading of 0.126 milliamperes maintained on Meter K by varying the distance between coils C and D.

Therefore the axial distance between these coils was a measure of the responsiveness of the tuning system, the relation between this distance and the field strength relative to that at a co-planar position being known.

Then this distance, corrected as above and plotted against frequency, gave resonance curves, giving the relative responsiveness or sensitiveness to different frequencies.

Three sets of tests were made:

1. Determination of resonance curve in first audion system only, meter K being substituted for coil F to give quantitative results.

2. Determination of resonance curve in second system only, coil G being coupled directly to coil D.

3. Combination of the two systems giving geometrical tuning.

The resultant resonance curves are shown on the accompanying prints.

Comparison of the resonance in the wave meter circuit alone to its resonance when it is actuated by another tuned audion circuit shows that its responsive range is widened, while sensitiveness to frequencies outside of this range is greatly cut down.

Theory predicts that the ordinates of the curve of the two tuned circuits should be the product of the ordinates of the curves of the two circuits alone, the peak of each wave being considered as unity.

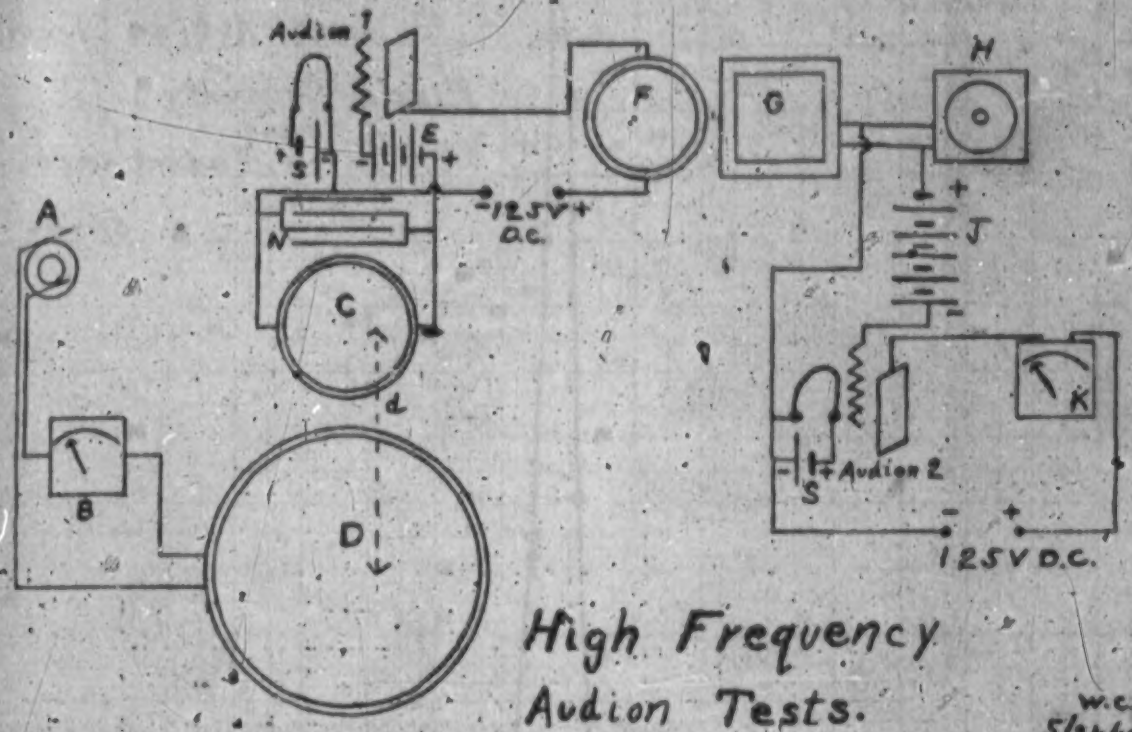
This checks up quite well on the lower portions of the curve, as the dotted line shows, but near resonance the high slope of the curves and the fact that the tuning of the component circuits was probably not closer than 2% prevents close agreement between the predicted resultant curve and the experimental.

The mere fact that sharp and consistent resonance results were obtained in the second circuit is ample proof that the improved audions are not sluggish in action. Tests made show that sharp tuning could be obtained at 105,000.

Witness:

M. E. CHRISTIE,
June 3, 1913.

WGW 9/25/13



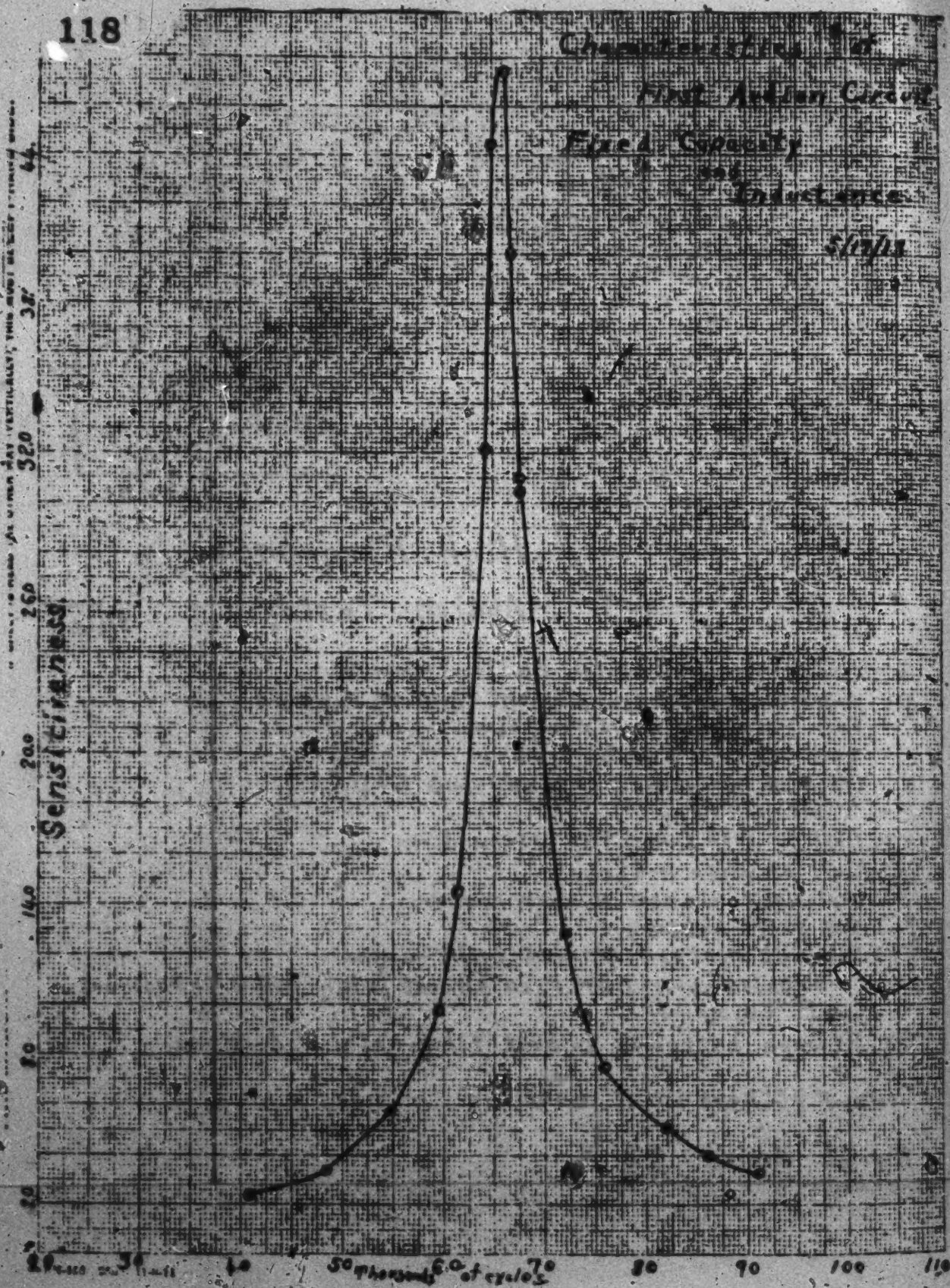
High Frequency Audion Tests.

W.C.W
5/24/13

A- High frequency alternator 20,000 - 100,000 ~
B- Hot wire ammeter current kept at 2.6 Amps
C- Coil 15 turns #16 15.5cm diam.
D- Coil 8 " #8 40.75cm "
d- Distance along axis between coils C & D.
E- 5 Volt battery
F- Coil 1000 turns #30 15cms diam.
G- Coil of wave meter.
H- Variable condenser of wave meter.
J- 7.5 Volt battery
K- Current meter 0-0.25 milli-amps.
N- Condenser, about .09 M.F. in circuit with coil C is resonant at 66,000 ~
S- Storage batteries to heat filaments of Audions.

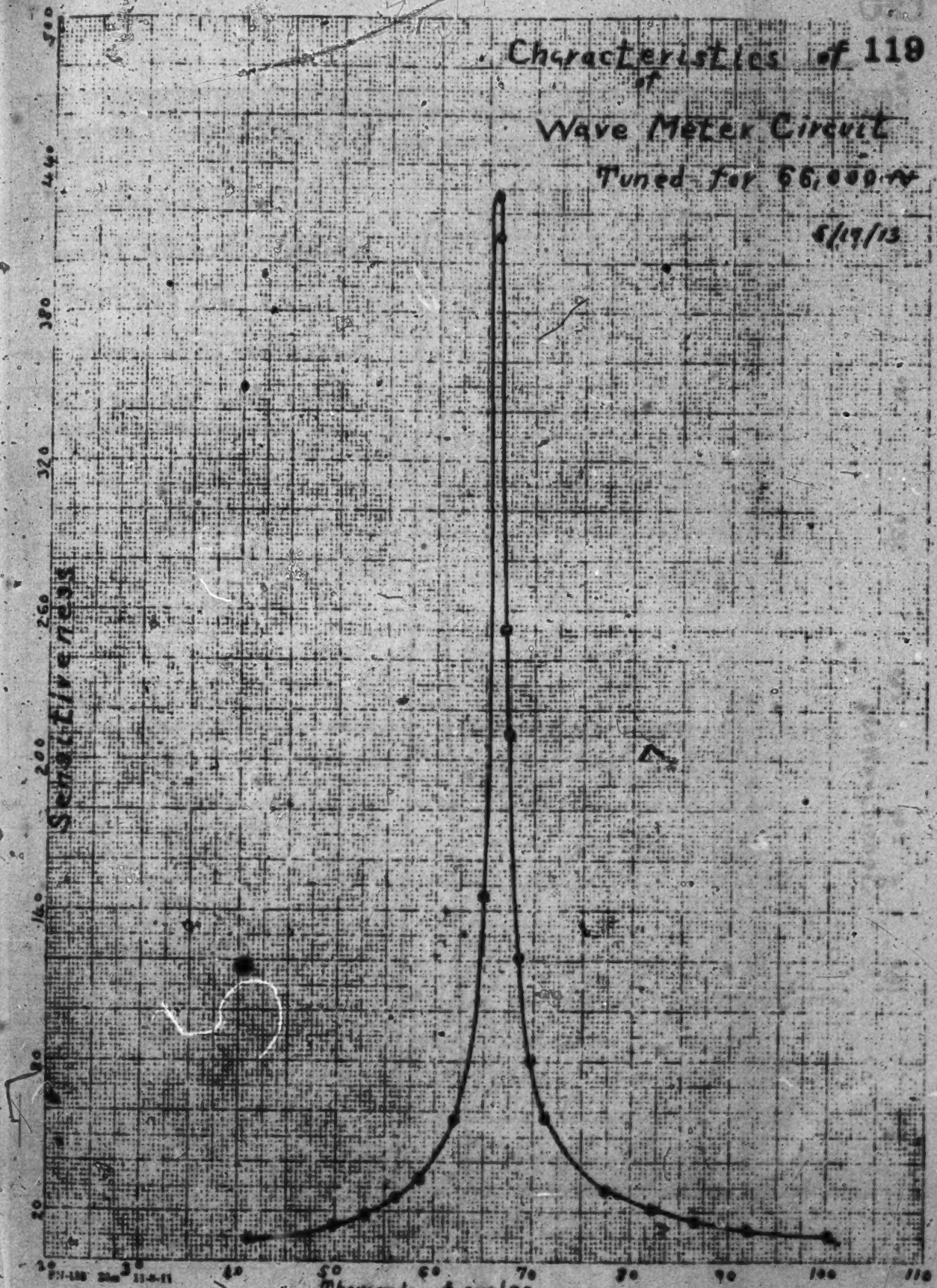
Coils F & G kept at 7" coupling

First Audion #8
Second " #2

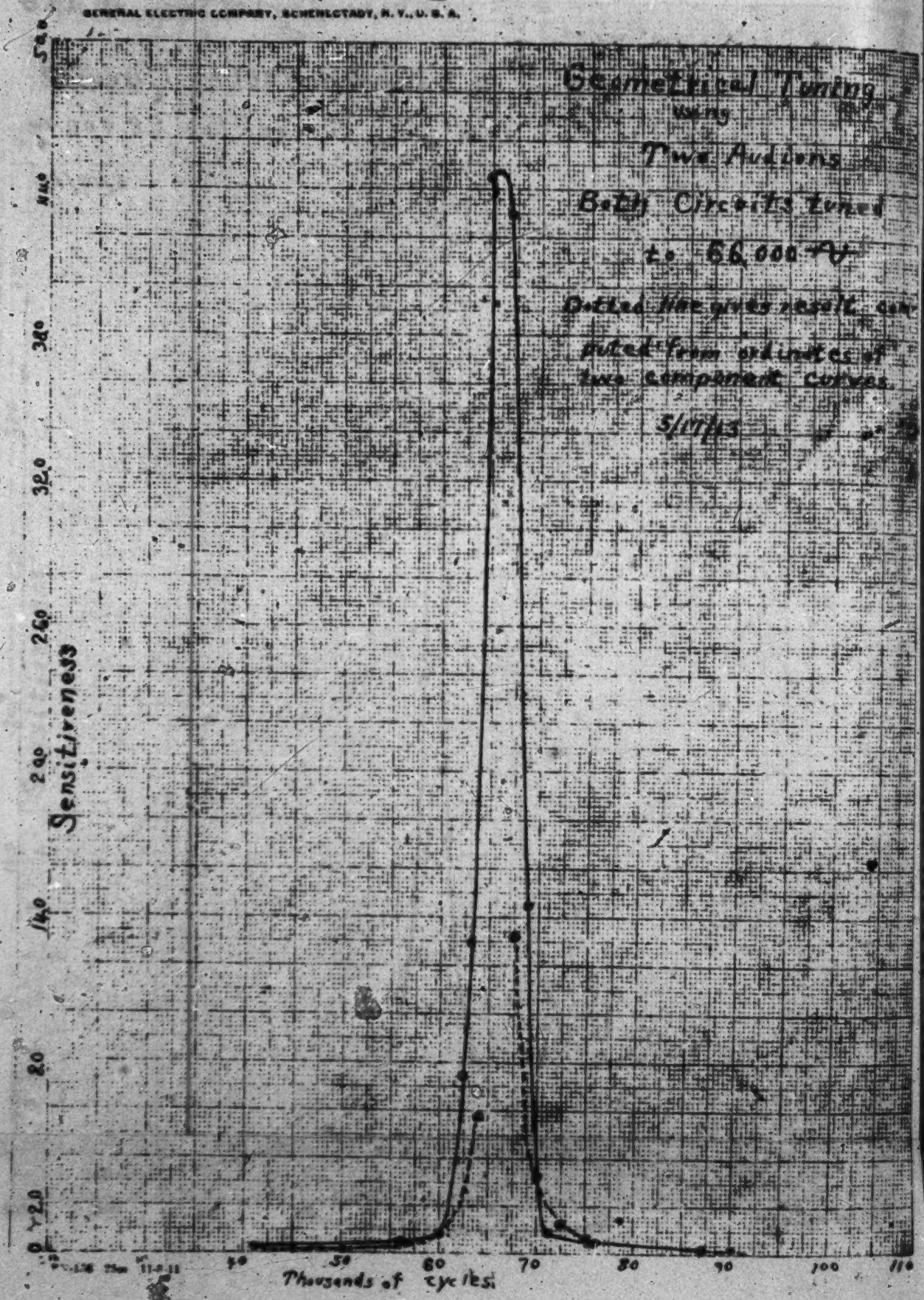

Characteristics of
First Audion Circuit
Fixed Capacity
and Inductance
Sharp
Sensitiveness
320
280
240
200
160
120
80
40
30
40
50 thousands
60 of cycles
70
80
90
100
110

Characteristics of 119
of
Wave Meter Circuit
Tuned for 66,000 ~

5/17/13



GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., U. S. A.



PLAINTIFF'S EXHIBIT No. 174.
Coolidge Note Book No. 327.

171

May 7, 1912

B. & S. Igniter

Platinum Contacts (Dec.)

May 8, 1912.

Received tube 5944#36 from Wiggin. This is my first tube with a tungsten cathode. It also has a tungsten anode, without any backing. It has the usual regulator but no auxiliary anode. Wiggin wrote that the tube was very freaky & would not do at all. My first impression was that it was by far the crankiest tube I had seen. Upon passing very little current thro it the vacuum would go from say 3 to 4 inches, and thro repeated strokes on and on.

The cathode got hot easily, and I finally found that with the cathode ~~running~~ at bright redness the tube showed entirely different characteristics. The vacuum became beautifully stable and, so far as to-day's duplicate shows it remains so as long as the cathode is kept at bright red heat.

172

I have the impression to-night that this tube shows much less heating of the glass around the cathode & also the fluorescent phenomena than do the regular tubes. I ran it a long while this afternoon getting intense X-rays. Behind the screen the light in the fluoroscope was very intense.

The perfect steadiness of the tube is remarkable. The glass shows a much deeper purple coloration than I have yet produced in any other tube.

The cathode shows no roughening unless it is at the very center over an area of perhaps $\frac{1}{16}$" diam. The heating at the cathode is clearly strongly localized at the center.

The tube, as it came, showed a black ring ~~around~~ on the glass around the cathode. This darkening has extended all over the tube to a slight degree. It may be due to cathode spattering of tungsten or it may be due entirely to the action of the regulator gases on W. I ~~have~~ ~~not~~ tested the action of the regulator gas before starting

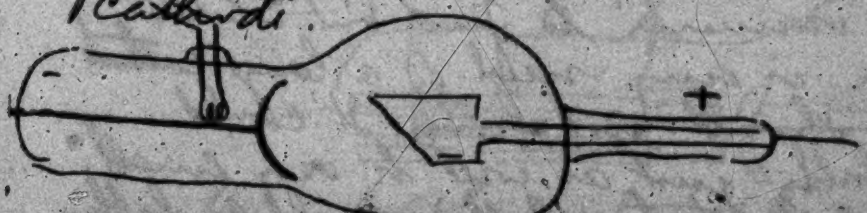
Wit
W. J. Gartner 173
Jan. 13, 1913

to run the cathode ray.

X I believe that the above points the way to the ideal X-ray tube. It looks to me now as though, with the hot tungsten cathode, the degree of vacuum would play an entirely subordinate rôle, provided of course it is high enough, and that there will no longer be any such thing as a too high vacuum. The tube resistance will apparently be determined by the temperature of the cathode.

To-day, to get the tube running, I had to use the regulator a couple of times. This was my only way for getting the cathode hot.

To-morrow I will get a tube started in which we can bring out the effect of a little incandescent tungsten filament behind and close to the cathode.



Current can be sent thru the filament from a storage battery, which is available

174

from the earth, and the filament can be electrically connected to the cathode.

Or a circular loop of W wire can be put around the cathode, but free from it except at one point & supported from the glass bulb surrounding the cathode rod

Read
W. J. Gartner
Jan. 13, 1913.

It will be very interesting with a very high vacuum to find out whether there is any need of a large cathode ~~this should not be so~~ It could probably just as well be very small. And the bulb (bulb) could probably also well be very small as it would not be necessary to make

it large for stability & vacuum. A small quartz bulb only 1 or 2 inches in diameter might well be plenty large enough for my high power work.

Tube 594036, described above, should, just as it is, readily permit of real moving picture work.

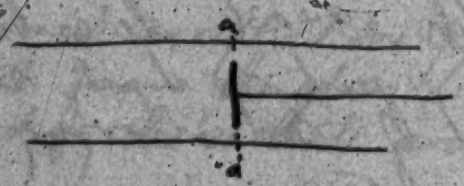
Heating of the cathode might well be made very easy by attaching a hollow stem to it and putting a coil of Chester Moore's thulth wire inside the hollow stem.

Another very simple thing might be to wind a tungsten spiral on a thin silica tube or alumina spiral and to slip this tube over the cathode supporting rod just behind the cathode

One end of the spiral could be connected to the cathode and other could be brought outside through the side of the tube wall

266

This was repeated over & over.
The tube is badly blackened near the target the blackening being



worst at a-a, with none behind here (the line is very sharp) and gradually decreasing towards the cathode.

Sept. 24, 1912.

Working with X-ray tube made up by Joe Hagen. W coil. Heavy W anode 7" bulb.

Tube is not on heater. Used Bunsen burner vigorously on it several times H_2 falling. Ran for about one hour on pump.

One effect shows up clearly starting with a vacuum of say 20 mm in the tube runs D.C. The electrodes boil heat up strongly, and there is a

as our Cadillac units were ready I would go with him to the Cadillac Co. & to Mr Kettering, to get them tested out.

Dr. Hubbard from Clark Univ. was here & tested at Collogquium on the rapid measurement of the period of oscillation in high frequency circuits.

Dec. 8, 1912.

If disapp. of gas in a tube is due to chem. action, dust should be more if it in case of a bulb of fused quartz. Test this out some more.

Dec. 10, 1912.

Dr. Langmuir tells me that, in his study of Edison Effect, the current, in the case of a short cathode, is greater with a very fine vacuum (of 1 or 2 hundredths of a micron Hg) than it is at higher gas pressures (excepting the case of argon). His Edison current to be obtained measurably at about 1600° C & get to a max. value at about 2300° C. I will try this out at once in an X-ray tube in which I can heat the cathode to any desired temp. The above would be in line with my observations on pgs. 171-675.

PLAINTIFF'S EXHIBIT No. 175. 59
Extracts From Coolidge Note Book No. 446.

Feb. 17, 1913.

Worked with Tube 11 x the G. M. It has a very small hole in the cathode plate (1/16 dia of curvature) with the filament just touching on to the hole and the target is placed much closer to the cathode.

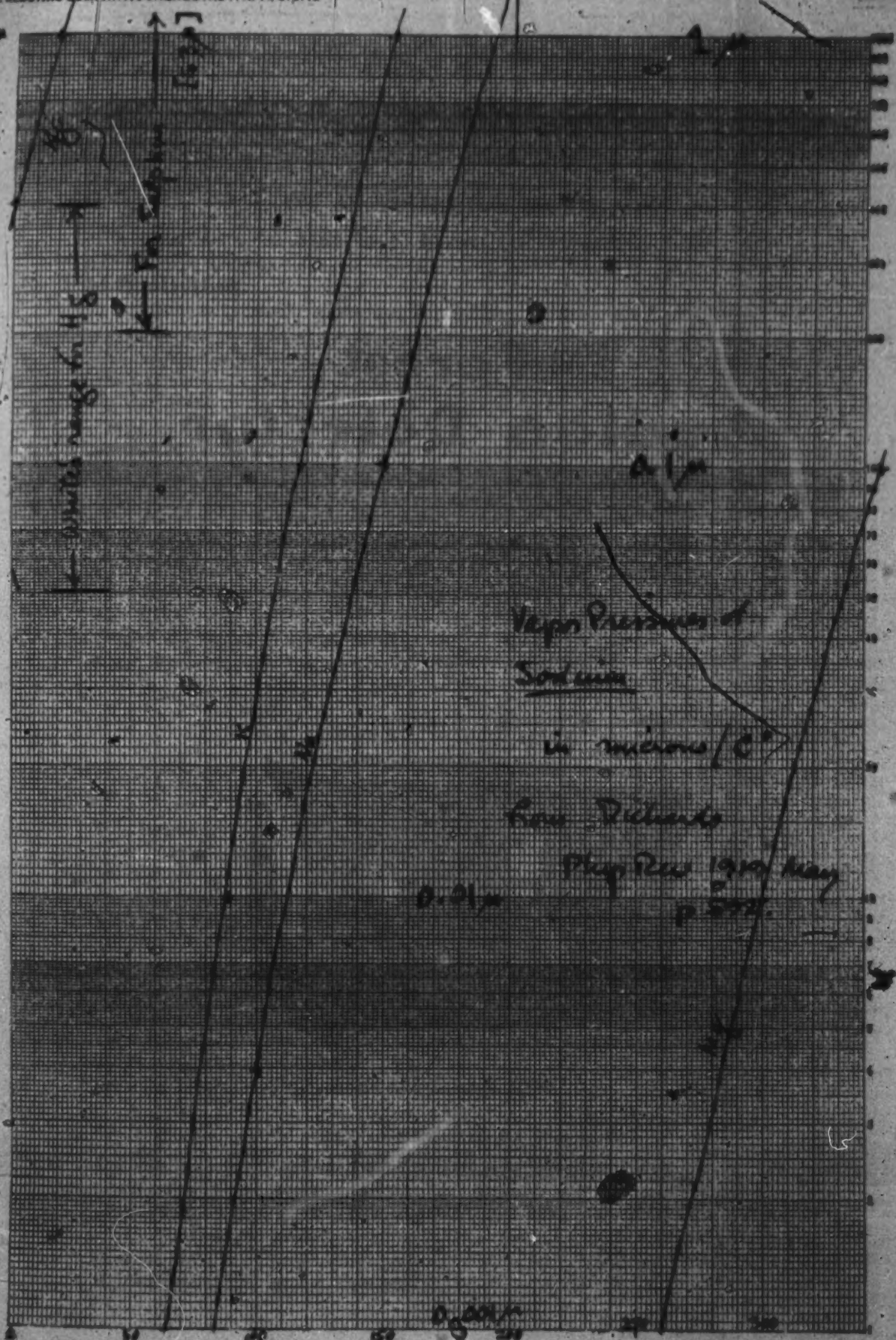
From the very first burning in of the current the tube has functioned sharply. As a result, it has been easy to heat the target so as to get the gas out of it. The tube was therefore in excellent condition after perhaps 1 hour's work on it after it had come out of the oven. The deductions were fresh ones, so that experiment demonstrated conclusively that the target has been the troublesome source of gas, and the fact of pumping when returning as an ordinary tube, that is before getting a good vacuum has been what has made the tube exhaust so tedious and precarious.

The new "1000" circuit will be completed by to-morrow morning, but can need for it is certainly lessened by to-day's test. It will clearly be much better to so design the tube that they shall focus in case the

PLAINTIFF'S EXHIBIT No. 176.

Hogan Diagram of Vapor Pressures of Sodium.

GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., U. S. A.

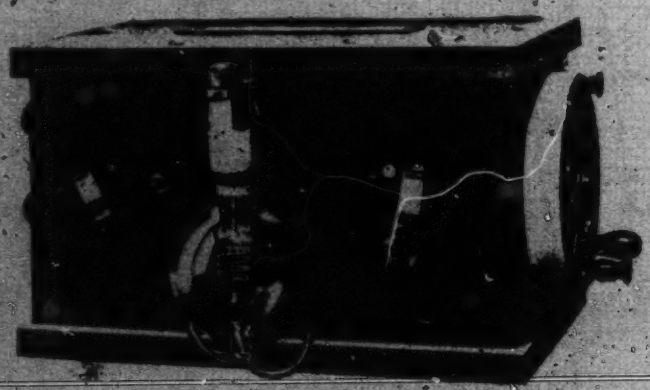


PLAINTIFF'S EXHIBIT No. 177.
DeForest Bulletin B-14 of 1914.

Bulletin B 14

DeForest Audion Detector

Licensed for private, amateur or experimental use only. The only Audion Detector manufactured for the use of amateurs under the protection of the patents of Dr. Lee deForest.



THE deFOREST AUDION DETECTOR
IMPROVED TYPE RJ4.

Licensed for Private Use Only

THIS instrument represents the highest development of wireless detecting apparatus known to science.

Tests conducted by the United States Bureau of Standards have shown it to be fully 30 per cent. more sensitive than any other form of detector (Bulletin, Bureau of Standards, Vol. 6, No. 3, P. 540).

Its adjustment is instantaneous, and is unaffected by mechanical or electrical disturbances.

This instrument is complete in itself, the only necessary connections being to the secondary terminals of the tuner, to the phones, and to a four volt battery. All these connections are plainly marked on the cabinet.

Throwing on the switch at the right of the Audion bulb to the left or right lights one or the other of the filaments. The battery switch at the left of the lamp and the rheostat lever are then moved to a position where signals are at their best. After these adjustments are once made, the throwing off of the switch instantly places the detector out of service. *Do not keep the Audion bulb lighted when not using the instrument.*

These detectors are thoroughly tested before shipment, and are guaranteed to leave our factory in perfect working order.

Price for the instrument complete as illustrated, $18.00

This detector may be operated by three dry cells. The best results, however, are obtained from the use of a storage battery.

4 volt 30 ampere hour storage battery, $5.00

THE deFOREST AUDION DETECTOR
TYPE RJ5.

Licensed for Private Use Only.

This instrument is complete in itself, the only necessary connections being to the secondary terminals of the tuner, to the phones, and to a four volt battery. All these connections are plainly marked on the cabinet.

Throwing on the two point switch at the right of the Audion bulb lights one of the filaments. The battery switch at the left of the lamp and the rheostat lever are then moved to a position where signals are at their best. After these adjustments are once made, the throwing on or off of the two point switch instantly places the detector in or out of service. After the first filament has been consumed wind the little copper wire tight around the brass base of bulb underneath the rubber band. This connects the second filament.

These detectors are thoroughly tested before shipment, and are guaranteed to leave our factory in perfect working order.

Price for the instrument complete as illustrated, $25.00

AUDION BULBS FOR RENEWALS.

The sensitiveness of Audion bulbs has been still further improved of late. We make two grades, the "S" or standard, and the "X" or extra sensitive. *Audion bulbs are sold only as renewals, or to those who have purchased our Audion Receiving sets,* and then only on the return of the old bulbs.

Renewal bulbs, "S" grade, $3.50 each.

Renewal bulbs, "X" grade, $5.00 each.

INSTRUCTIONS.

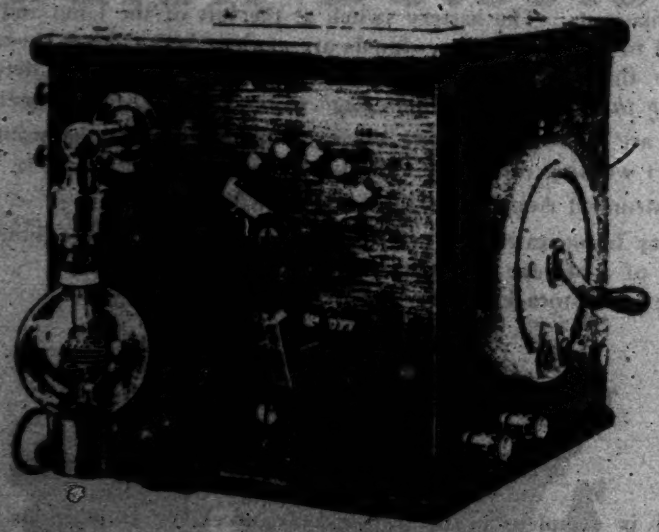
To get the very best results follow instructions explicitly.

Do not connect over six volts storage battery to the external binding posts marked + and —. Before lighting the filament see that the resistance switch is on the "IN" position. Then adjust rheostat until lamp burns at normal brightness. Adjust brightness of filament and the battery B switch to give maximum sensitiveness.

In connecting up the Audion Detector, connect the grid to G and wing to W, as marked below the binding posts. The Grid is the zig-zag wire terminal. The Wing is the plate.

If bulb is capped the green wire leads to the grid, the red leads to the wing.

Connect the little copper wire at base of bulb to the binding post directly beneath the bracket. This connects in the second filament to one point of the battery A, or lighting switch. The other filament is connected through the lamp socket to the other contact point. If one filament is more sensitive than the other reserve this for long distance work.



TYPE RJ6

The Audion has been proven, by scientific and official tests to be from 1.5 to 3 times as sensitive as any crystal detector. With it even in this small and cheap form, telegraphic ranges far greater than those possible with the crystal or electrolytic detectors are easily attained.

It is reliable, requires no adjustment after the proper voltage and heating currents are determined, it cannot be injured by powerful transmitter sparks in the immediate vicinity. If it momentarily loses its sensitiveness by reason of the transmitter spark, it is automatically restored, without the slightest decrease in its sensitiveness.

Receiving ranges with the Audion detector are far greater than with other types.

We have many testimonials from users of the Audion describing surprisingly long distances over which messages are being received, and the extraordinary strength of long distance signals.

If too much "Battery B" voltage be applied a blue glow will appear in the bulb, or may be seen merely around the edges of the "plate" or wing. When this blue glow fills the bulb it is usually not very sensitive. The glow can be removed by simply reducing the B voltage by the 3-point switch on the RJ4 and the 6-point switch on the RJ5. The sensitiveness can be instantly restored by merely switching off and on the lighting current. Only one filament should be burned at one time. This doubles the life of the bulb.

Never burn the filament at excessive brilliancy, as full sensitiveness can be obtained at normal brilliancy.

Always use a storage battery for lighting the lamp, as dry cells run down very quickly when used for that purpose.

Never use more than three cells of storage battery.

Don't let the storage cells run down low and then hook in another fourth cell, because if this is done there is always danger of the run-down cells picking up, or recuperating after a short period of rest and then of burning out the filament when first switched on again.

Connect the secondary of the receiver tuning circuit to the binding post marked "Tuner."

It makes some difference in the results obtained which of these two terminals is connected to one or the other of the two "Tuner" binding posts. The surest way of determining this is to reverse the two connections, and thus observe which gives the louder signals.

(The RJ4 and the RJ5 Audion are for *Amateur* work only and are *not* under any conditions licensed to be used for commercial work.)

We also manufacture other deForest Audion types as follows:—

Audion Detector, P.N. type, licensed for commercial work, each	$ 50.00
Audion Amplifier, one step, each	150.00
Audion Amplifier, two step, each	300.00
Audion Amplifier, three step, each	500.00
Combination Audion Detector and Amplifier, one step, each	200.00
Combination Audion Detector and Amplifier, two step, each	350.00
Combination Audion Detector and Amplifier, three step, each	550.00
Audion Bulbs, double grid and double plate, for renewals only, each	7.50
Variable Condensers, 3 type, each	55.00
Variable Condensers, 3½ type, each	35.00

Full description upon application.

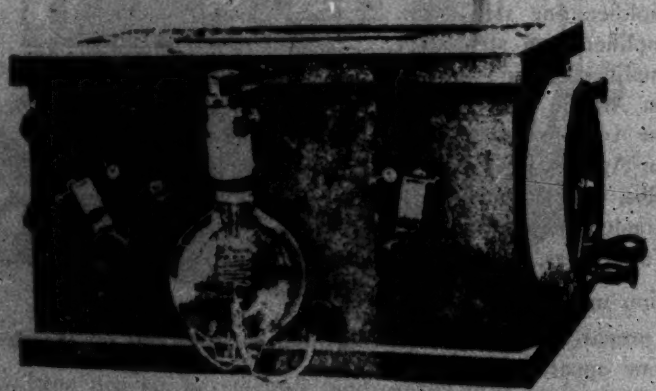
We are also prepared to submit estimates and specifications on Wireless Telegraph and Wireless Telephone apparatus.

PLAINTIFF'S EXHIBIT No. 178.
DeForest Bulletin B-15 of 1915.

Bulletin B 15

DeForest Audion Detectors, Variometers and the DeForest Audion Time Receiver

Licensed for private, amateur or experimental use only. The only Audion Detector manufactured for the use of amateurs under the protection of the patents of Dr. Lee deForest.



Improved Type RJ4 Audion Detector.

Manufactured by

DeForest Radio Telephone & Telegraph Co.
101 Park Avenue, New York.

Cable Address: Radiotel, N. Y.

REGARDING THE DEFOREST AUDION DETECTOR.

THIS instrument represents the highest development of wireless detecting apparatus. It is the most sensitive and reliable detector in existence. Tests conducted by the United States Bureau of Standards have shown it to be fully 50 per-cent more sensitive than any other form of detector (Bulletin, Bureau of Standards, Vol. 6, No. 4 P.540).

One of its greatest advantages over other detectors is its reliability. When once the proper voltage and heating currents are determined, no further adjustment is required. If powerful electrical impulses in the immediate vicinity should momentarily decrease its sensitiveness by their very strength, the Audion will generally restore itself at once automatically, but otherwise, turning the high voltage switch back one point and bringing it to its original position, will bring back full sensitiveness positively and at once.

The Audion Detector is not affected by any ordinary mechanical vibration and is not appreciably affected by the spark of the transmitting apparatus. It will stay in adjustment indefinitely and can be depended upon at all times. Its use enables the operator to receive over the greatest distances possible with any form of detector.

Each DeForest Audion Detector is supplied complete at the prices listed, with the necessary switches, rheostat, fixed condenser and the battery "B", *but without* the battery "A", which is composed of a six volt storage battery or three or four dry cells, preferably the former. *Never use more than six volts* for this battery, which is connected to binding posts on the outside of the case marked AA. All Audion bulbs have 3½ volt filaments.

The battery "B" is located inside the case and is composed of a number (from 10 to 12) of three cell flashlight dry batteries.

The proper methods of using the various styles of DeForest Audion Detectors, are described in this bulletin, and these instructions given for operating the detectors should be followed carefully if the highest efficiency is desired for the station.

All our Audion Detectors are regularly furnished with Standard "S" grade Audion bulbs. The "X" grade will be supplied at the additional prices as given in the PRICE LIST in this bulletin.

THE DEFOREST AUDION DETECTOR

IMPROVED TYPE RJ4

Licensed for Private Use Only.

This type of Audion Detector is now employed very generally in amateur stations. Like all our Audion Detectors, it is complete in itself with the exception of the Battery "A" which consists of a six or four volt storage battery, or three or four dry cells, preferably the six volt storage battery. Batteries may be purchased from any electrical supply house.

The Type RJ4 Detector is made in a mahogany case and now has a five point Battery "B" control switch instead of three points as shown in the illustration. This gives very close regulation and has greatly improved the efficiency of the detector.

This detector is recommended to those who desire to increase the receiving range of their stations, and who wish the greatest possible reliability of operation. Customers who have purchased Audion Detectors write us that they have discarded all other forms of detectors and use the Audion exclusively.

DIRECTIONS FOR TYPE RJ4 AUDION DETECTOR.

The proper method of connecting the Type RJ4 Audion Detector is described below. It may be used with any wireless receiving set, but best results are obtained with it in connection with a good receiving transformer, and a variable condenser. Simply connect the secondary terminals of the receiving transformer to binding posts on the Audion Detector marked "Tuner". Connect the telephone receivers to the binding posts marked "Telephone". The receivers for all types of Audion Detector should have a resistance of 1000 ohms or more each.

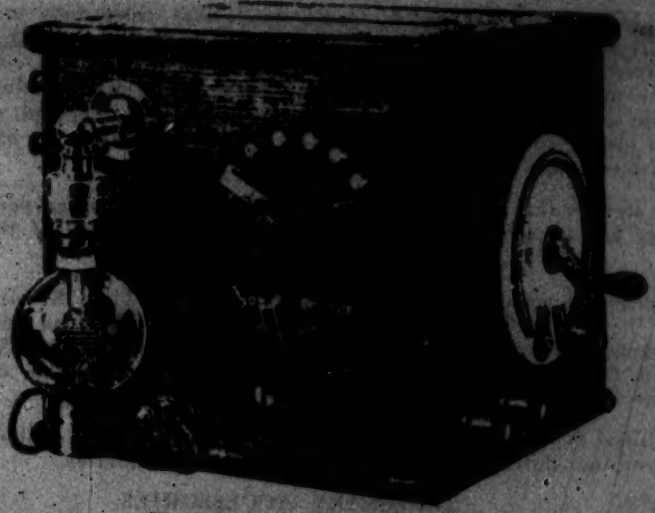
Turn the lever of the porcelain base rheostat (on the right hand end of the case) around to the left as far as it will go, so that it points downward and toward the front of the case. Screw the Audion bulb in the socket and connect the red wire (or wire leading out from the wing or plate of the bulb) to binding post marked R. Connect the green wire (or wire leading out from the grid or zig zag of the bulb) to binding post marked G.

The two point switch at the right of the bulb lights or extinguishes the filament. Light the filament and adjust the five point switch at the left, which controls high voltage battery "B" located inside the case until a slight hissing sound is heard in the receivers, when the filament is bright up to normal incandescence by means of the rheostat. Be careful not to burn the filament too brightly as this would shorten its life and will not materially increase its sensitiveness.

Each detector bulb has two filaments, one of which is connected in circuit when the bulb is screwed in the socket. When this filament burns out, the second is connected by simply twisting the wire projecting from the base, around the screw base and securing it under the rubber band.

Do not fasten any of our instruments by using screws long enough to penetrate the case. This might short circuit the internal condenser or batteries.

THE DEFOREST AUDION DETECTOR
TYPE RJ5.
Licensed for Private Use only.



Type RJ5 Audion Detector.

The Type RJ5 Audion Detector is a larger instrument than the Type RJ4 and is of higher grade construction throughout. The case is of oak with a dark waxed finish and all metal parts are heavily nickel plated. The switches are of four ply laminated construction, insuring positive contact, and the switch knobs are of genuine hard rubber. The battery "B" control switch has six points, permitting very close adjustment.

Instructions for operating and connecting this instrument are the same as for the type RJ4 Detector.

All our detectors are tested thoroughly before shipment and are guaranteed to leave our factory in perfect working order.

If too much battery "B" voltage is applied in any Audion Detector, a blue glow will appear in the bulb, or may be seen around the edges of the plate or wing, and a roaring sound will generally be heard in the telephone receivers. When this blue glow fills the bulb it is usually not very sensitive, and if this discharge is allowed to persist for a time, the bulb will become "hard", and will require a higher battery "B" voltage.

The discharge can be stopped by simply reducing the battery "B" voltage by the 5 point switch on the Type RJ4 or the 6 point switch on the Type RJ5 Detector. The sensitiveness can be restored instantly by switching off and on the lighting current.

A "hard" bulb can be "softened" by heating very carefully and evenly over a flame for a few minutes.

Audion Bulbs are sold for renewal purposes *for our instruments only* and then *only on return of an old bulb or the wing and grid system of an old bulb.*

Connect "Battery A", a 6 volt storage battery, or four dry cells, to binding posts AA, and try reversing these connections as this will make a difference. If dry cells are used, be careful to bring the rheostat lever back after using the detector, because the dry cells will recuperate on standing and their voltage will increase, which might burn out the bulb when turned on again.

Never use a higher voltage than 6 for this purpose.

Don't let the storage cells run down low and then hook in another fourth cell, because if this is done there is always danger of the run-down cells picking up, or recuperating after a short period of rest and then of burning out the filaments when first switched on again.

It makes some difference in the results obtained which of these two terminals is connected to one or the other of the two "Tuner" binding posts. The surest way of determining this is to reverse the two connections, and thus observe which gives the louder signals.

THE PURPOSE OF THE DEFOREST AUDION TIME RECEIVER.

Time signals are sent out by radio (wireless) telegraphy every day by the U. S. Government station at Arlington, a suburb of Washington, D. C., at 12 o'clock noon and 10 P. M., Eastern Time. These signals are simply a succession of dots, starting five minutes before the hours mentioned above and terminating in a dash; which begins exactly on the hour. No knowledge of the telegraph code is therefore required to obtain correct time, and this is a great advantage to anyone not skilled in wireless telegraphy.

These signals travel at the rate of more than 16,000 miles per second, so that an accuracy can be obtained which is greater even than that of the ordinary telegraph.

No license is required for operating our Audion Time Receiver and there is charge by the Government for the time service. Practically no knowledge of electrical apparatus is required to obtain excellent results with the Audion Time Receiver, and full directions are given in this bulletin to enable anyone to install and operate it.

The initial expense is practically the only expense, as the set should cost not more than three or four dollars a year to maintain, for new batteries.

NECESSARY ACCESSORIES.

The only accessories needed to form a complete time receiving station, in addition to our Audion Time Receiver, are a first class double head set wound to 2000 ohms or more, a quantity of aerial wire, a few aerial insulators, four dry cells or a six volt storage battery and a switch for connecting the aerial to ground when not in use, which is all that is required by the Fire Underwriters.

THE AERIAL AND GROUND.

Several types of aerial or antenna may be employed for receiving the time signals depending on local conditions. The higher the aerial wires are placed, and the longer, up to a limit of a 300 foot stretch, the better for the purpose and the louder the signals will be. Satisfactory results cannot be obtained generally with stretches of less than 100 feet.

Wherever possible, the flat top or the inverted L type should be used but the other forms may be employed if the former cannot be conveniently installed. Several good types are shown in the drawings. The aerial wires should be of stranded copper or some strong bronze, but iron or aluminum should not be employed for the purpose.

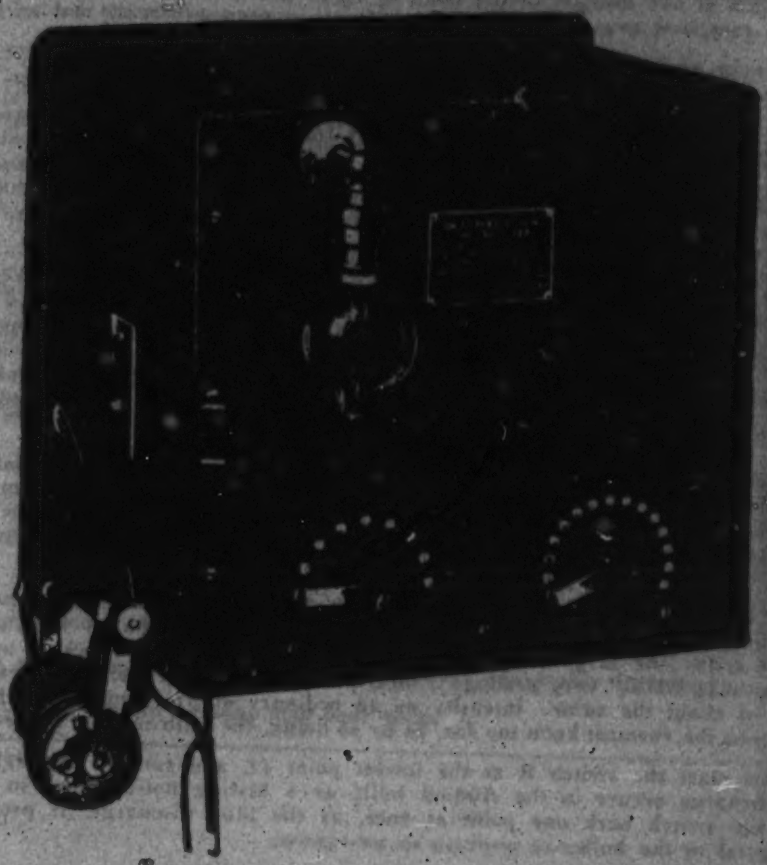
All aerial wires *must* be prevented from touching any objects except insulators, and the diagrams show the proper manner of supporting the aerial system.

A ground connection is best made by connecting to a city gas or water main by means of a ground clamp. When gas or water pipes are not available, a ground connection may be obtained by driving a one inch (not painted) iron pipe at least four feet into the earth in a moist place, and connecting to the pipe by means of a ground clamp. The wire leading to the ground connection need not be insulated.

The *Lighting Switch* has a special waterproof base. It is placed outside the building at the point where the continuation of the aerial wires enter, and is connected separately to the ground in a straight line, by means of No. 4 weatherproof wire. This is a different ground connection than the one for receiving purposes, and is made to an iron pipe driven into the earth at least four feet. The diagram shows the arrangement of the switch and its connections. It will be noted that when the blade is in one position, the apparatus is disconnected from the aerial which is connected to the earth, and in the other position the apparatus is connected to the aerial.

The switch should be left in the former position at all times when the apparatus is not in actual use, simply as a precaution.

THE DEFOREST AUDION TIME RECEIVER



The deForest Audion Time Receiver has been placed on the market to meet a strong demand for the highest grade, most serviceable set for receiving the Government time signals. It is designed primarily for this particular purpose, and will therefore, show a much higher efficiency for this work than any outfit made for general purposes of receiving messages.

This receiver uses as a detector, the famous deForest Audion Detector, which is the *most sensitive* and *reliable* device of its kind in existence (bulletin U. S. Bureau of Standards, Vol. 6, No. 4, p. 540). The deForest Audion Detector is the only highly sensitive detector which when once adjusted, will remain in perfect adjustment indefinitely, irrespective of mechanical vibration or the presence of powerful transmitting apparatus in the immediate vicinity. With its use the owner is assured of *reliable* service every day in the year, and at the greatest possible distance from the origin of the signals.

In addition to employing this peerless detector, we have combined, in a single case of waxed piano finish oak, the necessary tuning apparatus, so arranged that anyone can receive time signals positively and accurately without electrical knowledge or experience.

When once the set is adjusted, it will remain so from one end of the year to the other. When through using the set, simply hang the head receivers on the hook at the left so that it falls, which automatically shuts off all circuits, and when at any subsequent time it is desired to receive the time signals, lift the receivers off the hook at five minutes before noon or 10 P. M., Eastern Time, and place them over the ears, and you will hear the signals *every time positively* and *without fail*.

It is in reality a professional instrument, licensed only for private use. It measures 13 inches long, 11 inches wide and 11 inches high.

The case is of oak with a high waxed piano finish, all metal parts are heavily nickel plated, and all switch and control knobs and binding posts are of genuine hard rubber. The front panel is of black composition in great contrast to the nickel trimmings. The instrument is of such a high grade appearance as to harmonize with the very best of surroundings. From the standpoint of operating efficiency, it leaves nothing to be desired and the illustration shows its extreme simplicity.

DIRECTIONS FOR THE DEFOREST AUDION TIME RECEIVER.

Connect the wires running to the aerial through the lighting switch to the binding post on the set marked A. Connect the ground wire to binding post E. Turn the hard rubber knob under the lamp socket so that the pointer indicates "IN." Connect a six volt storage battery or four dry cells, preferably the former, to the binding posts marked AA. Connect the tips of the head set to the binding posts marked TEL.

Screw the Audion bulb into the lamp socket, and connect the wire leading out from the grid in the bulb to binding post G, and the wire leading out from the wing in the bulb to binding post R. (The grid is the zigzag of wire, and the wing is the metal rectangle.) If the wires leading from these parts are colored red and green connect the green wire to G and the red wire to R.

At five minutes before the hours on which the time signals are sent, Eastern Time, lift the head set off the hook and the bulb will immediately light. Turn the rheostat knob (the larger of the two directly under the lamp socket) away from "IN" toward "OUT," very gradually, until the filament of the bulb becomes normally bright, of about the same intensity as an ordinary electric lamp. Use great care not to turn the rheostat knob too far, as by so doing, the bulb will be burned out.

Now start the switch B at the lowest point 12, and turn to the right until a blue discharge occurs in the Audion bulb, or a hissing noise occurs in receivers. Bring the switch back one point at once, as the blue discharge, if prolonged, is detrimental to the bulb.

Move the switch knob PC from the lowest, left hand contact point, around the arc, in the meantime moving the knob LC slowly, until the high pitched time signals come in loudest. When this occurs, the set is in "tune" with the Arlington station.

If other signals should interfere with the time signals, simply turn the knob LC or VC to the left to reduce the interfering signals, and adjust slightly the switch knob PC for the best results.

No further adjustment will be needed. When finished, simply hang the head set on the hook, so that the light in the Audion bulb is extinguished, and the next time the correct time is desired, simply remove the head set from the hook and the signals will be heard without any adjustments whatever.

Do not leave the bulb lighted when it is not in use for this would reduce the life of the bulb.

If dry cells are used to illuminate the filament it should be remembered that in this service, their voltage drops off rapidly, and after standing, they will recuperate. Therefore, after using the set, the rheostat knob should be turned toward "IN" so that when the set is used again, the increase of voltage of these batteries will not burn out the bulb.

For other directions see those for types RJ4 and RJ5 Audion Detectors.

COST OF THE OPERATION.

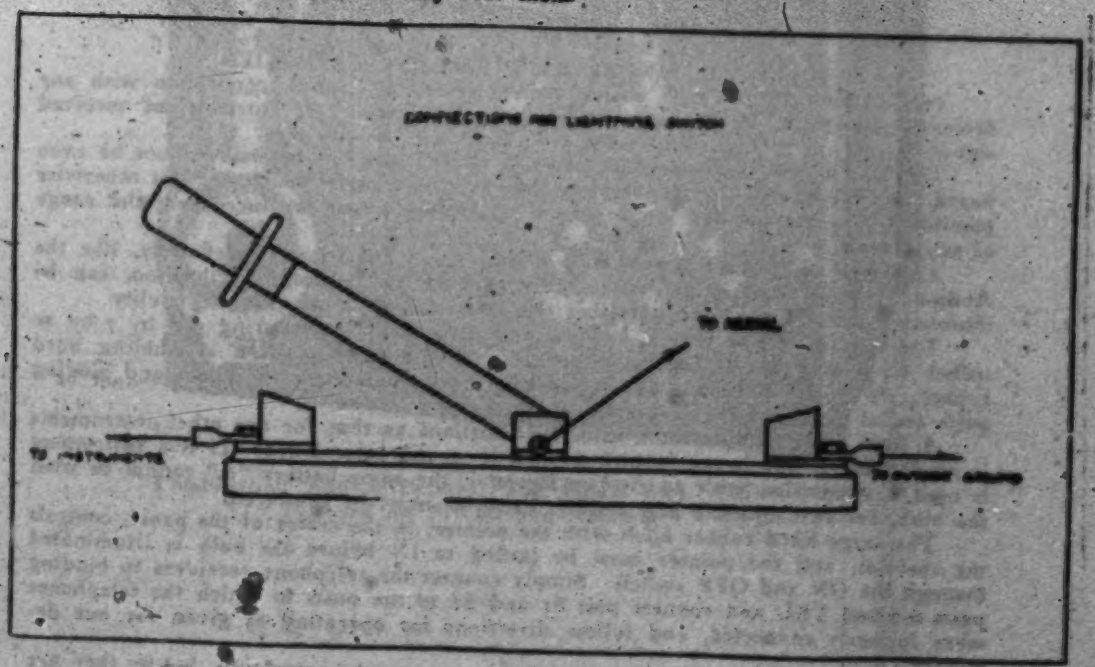
After a period of from eight months to a year, the small flash light batteries contained inside the case will become exhausted, whether the set is used or not. A new set of the common batteries can be obtained from any electrical house, and these may be readily connected in circuit. They must be connected in identically the same way as those now in the case.

The Audion bulb should last for a year or longer, if it is used for time signal reception only, and is not burned at excessive brilliancy. It will be noticed that each Audion bulb has two filaments. When the original filament burns out, the second is connected in circuit by merely twisting the fine copper wire around the brass base of the bulb under the rubber washer so as to make contact with the base.

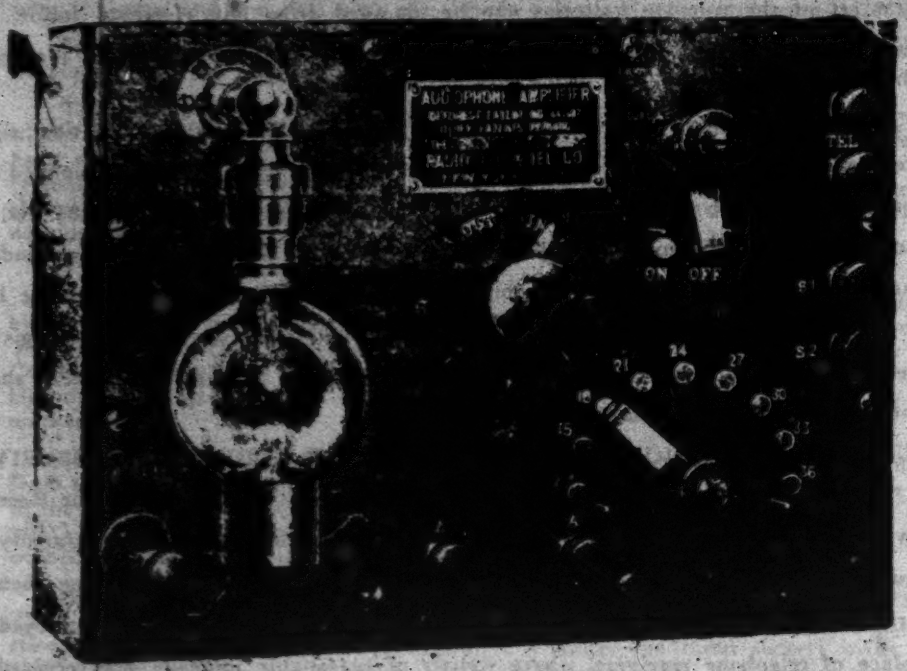
The batteries used determine their cost, but four good dry cells should give at least 30 useful actual operating hours, and a 30 ampere hour storage battery should provide 60 operating hours on a single charge.

USE OF THE AUDION AMPLIFIER WITH THE AUDION TIME RECEIVER.

The use of our Audion Amplifiers in connection with the Audion Time Receiver will permit reception of time signals where no other outfit can give satisfactory results. Wherever received signals are very weak, the amplifier will bring them in strongly, and if desired a loud speaking, high resistance horn may be employed in place of telephone receivers, where signals of reasonable intensity are received, so that any number of persons may hear them.



THE SINGLE STEP AUDION AMPLIFIER
Licensed for Private or Amateur Use Only



TYPE PJ1 SINGLE STEP AUDION AMPLIFIER.

The Audion Amplifier is an instrument which is used in connection with any detector, preferably an Audion Detector, for increasing the intensity of received signals from 5 to 10 times. It is not a detector itself in any way.

Through its use, messages can be read clearly which otherwise cannot be even heard. Its use enables the operator to receive over ranges which are not otherwise possible. It is the greatest improvement of modern times for increasing the range of any station.

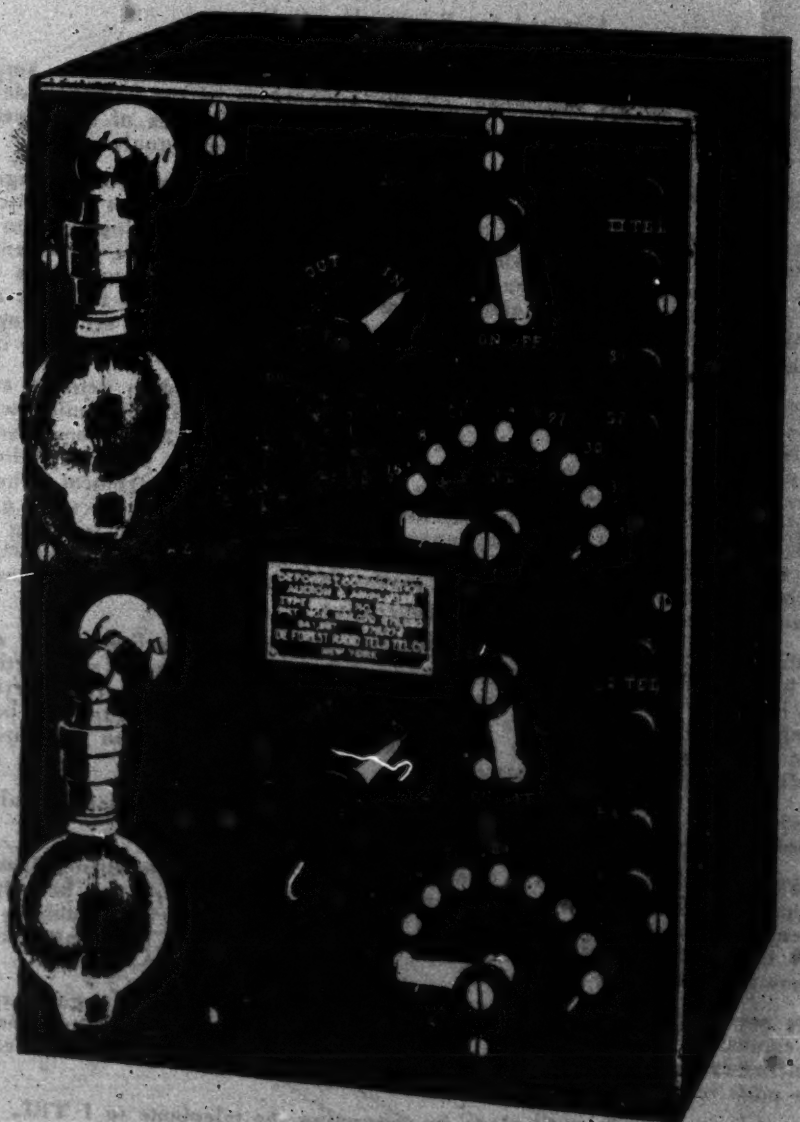
This type of Audion Amplifier will remain in adjustment indefinitely, like the Audion Detector, and is not appreciably affected by mechanical vibration, can be thoroughly relied upon, and amplifies the weak signals with absolute fidelity.

The case is of oak with a high waxed piano finish, measuring 9¼ by 7 by 10 inches deep over all. The front panel is of black composition resembling hard rubber. All metal parts are heavily nickel plated and the switch knobs and binding posts are of genuine hard rubber.

A local battery "A" of the same specifications as that for our other instruments is needed for it but is not furnished with it at the price listed. If this instrument is used in connection with an Audion Detector, the same battery "A" cannot be used for both, but two separate and distinct batteries must be employed.

The large hard rubber knob with the pointer, in the center of the panel, controls the rheostat, and the pointer must be turned to IN before the bulb is illuminated through the ON and OFF switch. Simply connect the telephone receivers to binding posts marked TEL and connect post S1 and S2 to the posts to which the telephones were formerly connected, and follow directions for operating as given for our detectors.

Both filaments of the Amplifier Bulb are used at the same time, but as they are burned at a lower temperature than those of an Audion Detector, they have a very long life.



Combination Audion Detector and Single Step Audion Amplifier
Licensed for Private and Amateur Use Only.

COMBINATION AUDION DETECTOR AND SINGLE STEP AUDION AMPLIFIER.

Licensed for Private Use Only.

In this instrument are combined an audion detector and single step amplifier, giving the operator in one instrument all the advantages of the ordinary deForest Audion Detector (in itself from 1.5 to 3 times the sensitiveness of the crystal or electrolytic detectors) plus a five-fold amplification of these signals.

Equipped with this combination set an operator has an immense advantage over all those who use other types of detectors. We find this instrument is particularly attractive to all the higher class of operators, as in addition to enabling them to easily read stations many hundreds of miles further than can their neighbors, it tremendously simplifies the labor, and heightens the pleasure of wireless receiving. This on account of its utter dependability, and freedom from all delicate and frequent adjustments. When once the battery switch and rheostat are correctly set the operator *knows* that if he is once tuned to the distant station he will hear it *every time* it calls.

Moreover, on account of the extreme efficiency of the Audion detector and the negligible damping which it adds to the secondary receiving circuit, tuning with the Audion is much sharper than with other forms of detectors. Much looser coupling may be used, with corresponding freedom from interference. Especially does this last feature hold for the combination detector and amplifier instrument, wherewith it is easily possible to couple so loosely that all signals, and static as well, are first rendered entirely inaudible with any unamplified detector, and then to bring up the signals (especially if slowly damped wave-trains be used) to a full audible intensity. By this means it is possible to read long-distance messages through static disturbances which render other forms of receivers inoperative.

In this connection we recommend increasing the damping qualities of the antenna system, by inserting therein a variable non-inductive resistance (as practised by Dr. Austin of the U. S. Bureau of Standards) to render same as nearly a periodic to static impulses as possible. It is then found that the Amplifier can still bring up the strength of signals over that of the static more than enough to compensate for their reduction by this added resistance.

Combinations of the Audion Detector with the two-step Amplifier and also with the three-step Amplifier are made.

The case of this instrument is of oak, with a high waxed piano finish. It measures approximately 9½ by 18 by 15 inches over all. All metal parts are heavily nickel plated and all switch knobs and binding posts are of genuine hard rubber.

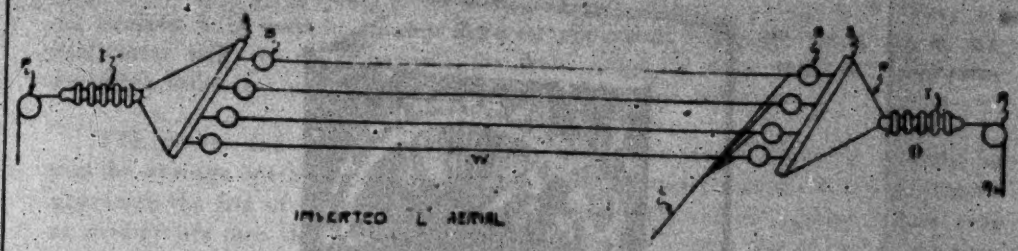
The lower bulb is that of the detector, and the upper one is the amplifier bulb, which has two grids and two plates.

The secondary terminals of the receiving transformer of the regular receiving set are connected to binding posts RA and RE. Reversal of these connections sometimes increases the efficiency of the set. A large variable condenser also connected to these posts is of great value in tuning.

The detector may be used alone by connecting the telephone to I TEL. If both detector and amplifier are to be used, connect this pair of binding posts to posts S_1 and S_2, and connect the telephone to posts II TEL. Each bulb has its individual control switches. B_1 and B_2 control each battery "B," and each bulb has its own rheostat lettered OUT and IN.

All other directions for operating are the same as given herein for the Types RJ4 and RJ5 Audion Detectors.

Try reversing connections of both "A" batteries for best efficiency. Two separate "A" batteries are required for this instrument.

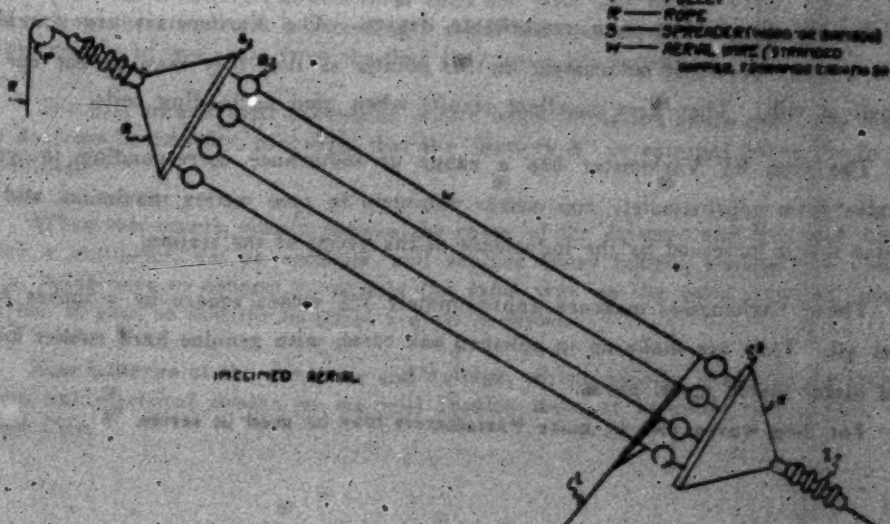


INVERTED 'L' AERIAL

'T' AERIAL

KEY

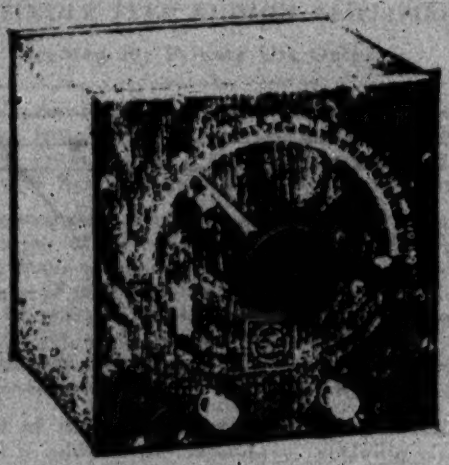
B — SMALL INSULATOR
I — 10 INCH INSULATOR
L — "LEADING IN" WIRES
P — PULLEY
R — ROPE
S — SPREADER (WOOD OR BAMBOO)
W — AERIAL WIRE (7 STRANDED COPPER, 7 SWG PER STRAND)



INCLINED AERIAL

DEFOREST VARIOMETERS

TYPE RJ



DeForest Variometers represent one of the most modern and efficient means of tuning sharply to incoming signals. They have no "dead ends," as all the wire is used all the time. There are no switch points or sliding contacts to cause waste of the minute received currents through their resistance.

These Variometers are extremely sharp in tuning. They give excellent results through interference, and are recommended to every operator. They may be placed in a vertical position or horizontally as they are balanced so that they remain in any position where set. All adjustments are made with a single hard rubber knob, which simplifies tuning to a remarkable degree. The Variometers are provided with a short circuiting attachment on the pointer so that they may be cut out of circuit at will. They give excellent results when used as loading coils.

The type RJ Variometer has a range of inductance corresponding to wave lengths from approximately 200 meters minimum to 1500 meters maximum, and of course this is increased by the inductance of the aerial of the station.

These Variometers measure approximately 7¼ inches square by 9 inches high over all. They are made up in polished oak cases, with genuine hard rubber knobs and nickel plated metal parts.

For long waves, two or more Variometers may be used in series.

RENEWAL AUDION BULBS

Audion Bulbs are sold *for renewal purposes, for our instruments only, and then only on return of an old bulb or the wing and grid system of an old bulb.* They are not licensed to be used in any but deForest apparatus, and under positively no circumstances will we be responsible for their action in other than our apparatus. Amplifier Bulbs are not renewable in place of detector bulbs.

The quality and life of Audion Bulbs have been much improved recently, so that the average operating life is about 800 hours if properly used. While we cannot guarantee the life of a bulb, actual tests of bulbs selected at random showed even as greater life than this. So much depends upon the proper use of bulbs, however, that no guarantee of life can be given.

Audion Bulbs are furnished in two styles—those of standard degree of sensitiveness (style "S") and those of especial sensitiveness (style "X"). Every bulb is given two tests before leaving our factory, against a standard.

Amplifier bulbs are supplied only in "X" grade, in tantalum filament and Hudson or tungsten filament types. The latter types have from two to three times the operating life of tantalum filament bulbs.

Each bulb is packed with extreme care, and we cannot be responsible for breakage in transit. In general, very few bulbs are damaged in this way, and when this does occur, the plate simply becomes jarred out of line. It can be brought back easily by simply tapping the bulb against the hand in the proper direction, taking care that the plate and grid do not strike the filament.

RENEWAL BATTERIES FOR "BATTERY B" IN ALL DETECTORS AND AMPLIFIERS.

In each Audion Detector and Amplifier a number of flashlight batteries are contained. Each battery contains three cells and tests four to five volts. The current taken from these batteries is exceedingly small and they therefore generally last from eight months to two years from the time they leave our factory.

The first sign of their exhaustion occurs when received signals gradually weaken or decrease in intensity, providing that the "Battery A" or external battery is in good condition.

When this occurs, simply remove the cover of the detector and test each battery with a voltmeter, *not an ammeter*, and replace every battery testing four volts or less, being sure to connect in exactly the same way as the cells removed, that is, carbon to zinc, so that the batteries are all in series.

New batteries of the same size and voltage, which *must* be used, can be obtained from any electrical dealer, or we will furnish them at 25 cents each F.O.B. New York City.

PRICE LIST F.O.B. NEW YORK, N. Y.

Type RJ4 Improved Audion Detector	$ 18.00
Type RJ5 Audion Detector	25.00
Type PJ1 Single Step Audion Amplifier	65.00
Combination Audion and single step Audion Amplifier	110.00
DeForest Audion Time Receiver, less Telephones and Accessories	75.00
Special High Resistance Loud Speaker Telephone with Horn	50.00
Type RJ DeForest Variometer	20.00

Renewal Audion Bulbs*

Type S, Standard Grade Audion Bulb	3.50
Type X, Extra Sensitive Audion Bulb	5.00
Renewal Amplifier Bulb (Tantalum Filament)	6.00
Renewal Amplifier Bulb (Hudson Filament)	7.50

Above prices subject to change without notice.

We are in a position to furnish all accessories needed for the deForest Time Receiver, and will submit prices on request.

*AUDION BULBS WILL NOT BE SOLD OR LICENSED TO BE USED EXCEPT WITH OUR APPARATUS. Renewal bulbs supplied only on return of the wing and grid system of our burned-out bulbs.

All forms of Audion, Amplifier and Ultraudion protected by the following U. S Patents granted to Lee de Forest.

824,637	836,070	837,901	841,387	867,877	879,532	943,969
824,638	836,071	841,386	867,876	867,878	979,275	995,126

Other Patents Pending.

Most wireless dealers handle our Audion Detectors and Amplifiers. Write us for name of nearest dealer.

If your dealer does not carry a stock of our instruments, he will order them for you, or otherwise we shall be glad to receive your order direct.

The price of Hudson and Tungsten filament Audion detector bulbs has been reduced to the old prices of tantalum filament detector bulbs.

PLAINTIFF'S EXHIBIT No. 179.
DeForest Bulletin C-16 of 1916.

Bulletin C 16

De Forest
Type T Tubular Audion Bulb

"There is only one Audion - The De Forest"

Manufactured by

DeForest Radio Telephone & Telegraph Co.

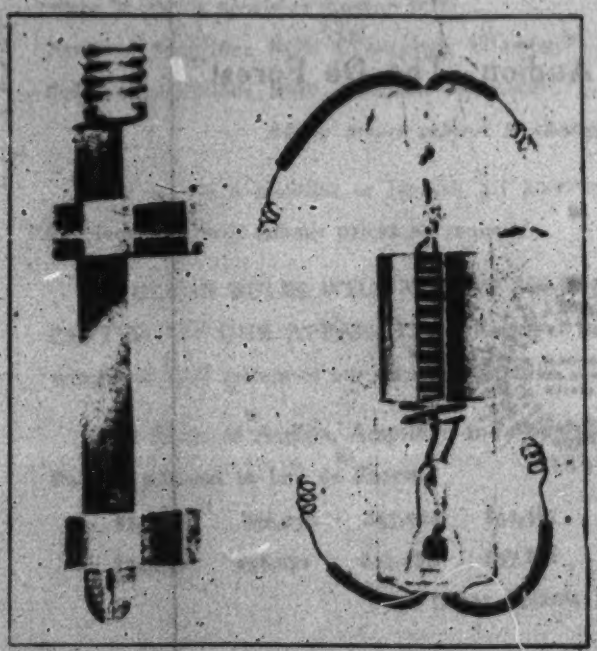
Sales Office 101 Park Avenue,
New York.

Cable Address: Radiotel, N. Y.

"THERE IS ONLY ONE AUDION—THE DE FOREST."

The Audion Detector is the most sensitive detector in existence. The Bulletin of the U. S. Bureau of Standards, Vol. 6, No. 4, Page 540, states that it is fully 50 per cent. more sensitive than any other known form of detector. It is the only reliable sensitive detector.

For the benefit of those amateurs who desire to experiment, and who do not wish to buy complete Audion Detectors with the necessary accessories, and for those whose limited means will not permit the complete instruments to be purchased, we have brought out the Type T Tubular Audion Bulb.



Commencing March 15th, 1916, this type of Audion will be sold separately, without the other parts necessary for a complete Audion Detector. It is licensed for amateur use only and is NOT interchangeable with the regular round Audion Bulbs.

This type of Audion Bulb gives very loud response to signals. Every bulb passes two tests by our experts and is thoroughly up to our standard of sensitive qualities. It is finished in only one grade—the best.

The life of the Type T Tubular Bulb is exceptionally long on account of the fact that the single straightline filament has no loops, and as there is no second filament, the Edison discharge to same is completely eliminated.

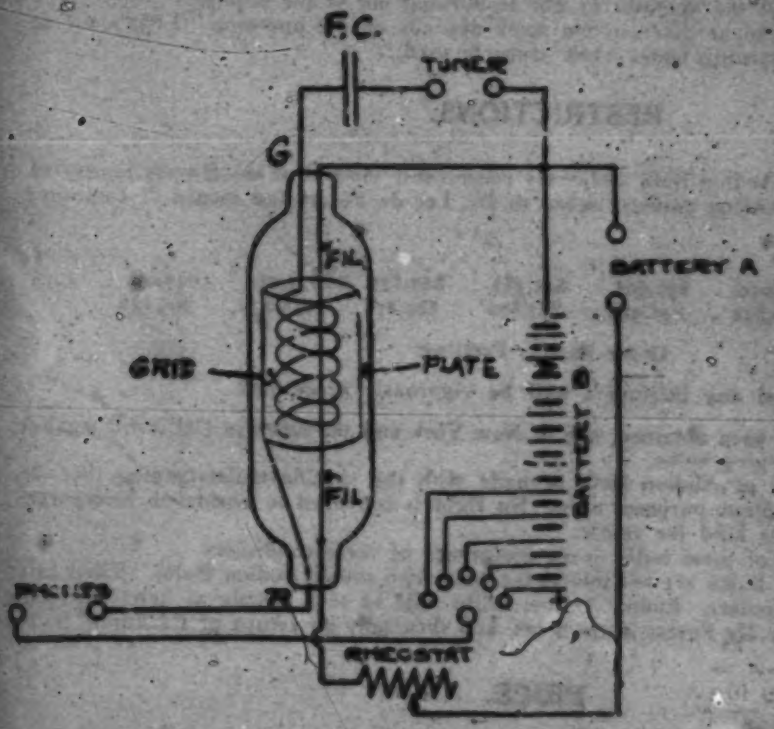
The plate or wing is in contact with the glass, preventing overheating. The filament is surrounded by a spiral grid.

This type of bulb is an excellent oscillator for the reception of continuous waves, being different in this respect than round Audion Detector Bulbs.

The grid is the spiral inside the tube and is connected to the green covered wire. The plate is connected to the red covered wire. The filament terminals are the white covered wires.

DIRECTIONS FOR USING
THE TYPE T TUBULAR AUDION BULB.

1. The diagram below illustrates the various accessories needed with the bulb. The rheostat is an ordinary battery rheostat, furnished by electrical supply houses. Battery B consists of 10 three cell flashlight batteries, each showing at least 3½ volts on a *voltmeter*. They are connected in series, with zinc of one to carbon of the next, and so on throughout the series. It is very important that each shows at least 3½ volts to 4½ volts and that they are properly connected together, otherwise the results will be very poor. The negative or zinc end of this battery *must* lead to the filament.



A switch is to be arranged as shown to cut in 6, 7, 8, 9 or 10 batteries at will.

The fixed condenser F.C. consists of two sheets of tin foil 4 inches square, separated by a *mica* sheet. This *must* be of first-class construction and of small capacity. A *small* variable condenser may be substituted.

Battery A should be a 6 volt storage battery of at least 30 Ampere hours capacity. Two sets of dry cells, each having 4 cells may be arranged in parallel instead, but the storage battery is recommended.

CAUTION

Do not permit either of the filament wires to come in contact with any circuit or any metal part carrying current. This might connect A to the Battery B and burn out the filament. *No credit* can be offered for a bulb burned out from *any* cause.

2. The bulb *must* be operated in a vertical position to give best service.

3. Always turn in all resistance on the rheostat before lighting the filament. Batteries recuperate on standing idle and the increase of voltage might burn out the filament.

4. Adjust rheostat to give normal filament brilliancy and adjust Battery B switch to best point. Then try reversing current from the lighting battery to find out which direction is better.

5. The bulb is most sensitive at a point just below that at which the hissing sound is heard in the telephones.

6. The receivers should be each of at least 1000 ohms resistance.

7. FOLLOW THESE DIRECTIONS TO THE LETTER. They are important.

GUARANTEE.

We guarantee the Type T Tubular Audion Bulb to have been tested by our expert and to have passed our standard which is fully 50 per cent more sensitive than any crystal or electrolytic detector, when leaving our factory.

We guarantee these bulbs to arrive in good condition. If a tubular Audion Bulb is broken in transit when shipped by us, and is returned *at once*, it will be replaced.

We will *not* replace any bulb for any other reason, whether due to breakage on account of negligence on the part of the operator or due to burning out of the filament.

No *guarantee* of life can be given as too much depends on the operator. Tests show an average life of over 800 burning hours when properly used.

RESTRICTIONS.

This and every other Audion Bulb and every conceivable method of using same is covered by one or more of the following patents, issued to Dr. Lee de Forest and owned or controlled by this company.

824,637	836,070	837,901	841,387	867,877	879,532	943,696
824,638	836,071	841,386	867,876	867,878	979,275	995,126

Other Patents Pending.

All and any infringers will be vigorously prosecuted.

Two injunctions have been obtained, one in New York and the other in California against makers and users of infringing bulbs.

The sale of this type of Audion Bulb is made with the specific understanding that the bulb is to be used for amateur purposes only. No right is conveyed to anyone to incorporate this bulb in any set of any kind for resale.

The purchase of one of these bulbs is an acceptance of these conditions.

The Type T Tubular Bulbs are not interchangeable with round Audion Bulbs. Their sale is entirely separate and distinct. Round Audion Bulbs will be sold exactly as heretofore, for renewal purposes only for De Forest instruments, and then only on return of De Forest Bulbs of similar type.

PRICE.

The price of the Type T Tubular Audion Bulb only is $5.50. The adapter to fit it to a screw socket will be furnished at 40 cents extra. It is not necessary to return the burned out bulb for renewal.

This Bulb and our other receiving equipment is furnished by 45 distributors conveniently located throughout the country. Name of nearest distributor furnished on request.

Write for Bulletins on Audion Detectors, Amplifiers and Receiving Sets if interested.

DE FOREST RADIO TELEPHONE & TELEGRAPH CO.

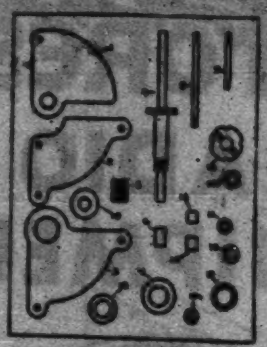
Sales office

101 Park Avenue **New York, N. Y.**

PLAINTIFF'S EXHIBIT No. 180.

DeForest Catalogue L.

Knock-down Condenser Parts



Complete sets of parts for CV-500 Condenser .0005 Mfd. Price, $3.00 *Code Word:* LAMBENER. *Shipping Weight:* 1 pound.

The numbers in parenthesis refer to diagram. The other numbers to number of parts required:

(1) 12 Rotor plates (2) 13 Stator plates (3) 2 End plates (4) 1 Shaft (5) 2 End bearings (6) 3 Large filler posts (7) 4 Insulating collars for lock nuts (8) 3 Stator plate rods (9) 1 Rotor plate rod (10) 4 End lock nuts (11) 36 Stator separators (12) 2 Hard rubber collars (13) 3 Round tie rod nuts (14) 3 Small filler posts (15) 12 Large rotor separators (16) 2 Small friction washers (17) 2 Flat washers (18) 1 Rotor nut (19) 11 Rotor separators (20) 3 Hex nuts (21) 2 R. H. Brass screws (22) 1 Flexible shunde wire.

Radio Frequency Transformers for Reflex Sets

The Transformers illustrated are sold singly or in sets for use in the Reflex circuit. These are laboratory precision parts, made with the care characteristic of all De Forest equipment. They are numbered to indicate the position in the circuit. Price, $2.50 each.

De Forest Combination Detector Amplifier Audions — Type DV-6 Vacuum Tubes

This new tube is of the metallic vapor t operates without injury from 2½ to 6 volts dry batteries or storage batteries. It may with any standard circuit and in any type of ing apparatus without any change in wiring tube is as near a universal one as it is po obtain. It functions with equal efficiency a tector or an amplifier of audio frequency. It possible to use this tube successfully in ra quency circuits. It has small elements, there capacity, which is a very desirable feature fo frequency work.

These tubes are so called "hard" or gas fr because of this they are stable in their op They are excellent oscillators and have sufficie put so that they may be used as radio frequen erators for measuring purposes. The filame sumption is small being approximately 2.8 wat depending on the use to which the bulb is put operated as a detector, the filament current

than when operating as an amplifier. It is recommended that 40 volts be used on the plate when this tube is used as a detector and 40 to 60 volts when used as an amplifier. When working with a fully charged storage battery, never turn the rheostat on full. This tube should never be operated with more than five volts on the filament:

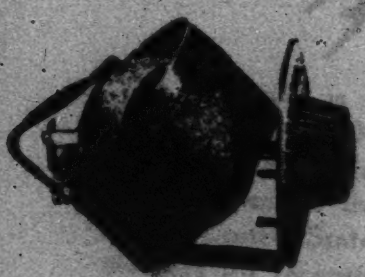
Filament 5 Volts; 5/10 of an ampere.

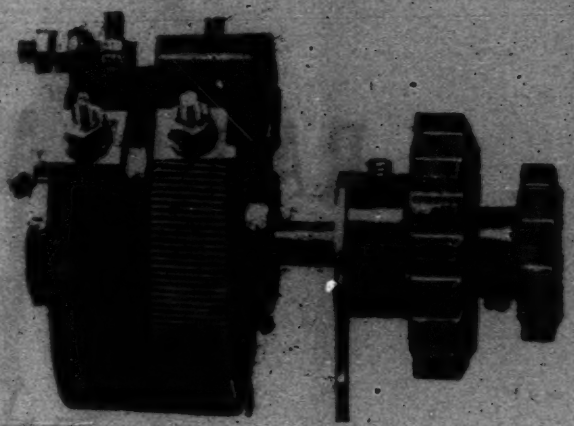
Plate Voltage, 40 to 60 Volts. Price $6.00.

Code Word: ANDA *Shipping Weight:* 8 ozs.

De Forest VL 180° Variocoupler Unit

This variocoupler is similar to that which has given such universal satisfaction in the De Forest D-7-A Reflex Receiver. It has twice the tuning efficiency of a 90 degree coupler, and quantity production has made it possible to sell this high quality laboratory tested product at a lower price than this type usually commands. Its wavelength range is 150 to 700 meters; it takes up only the amount of panel space necessary for its three inch dial; all metal parts are of brass, heavily nickel plated; solid Bakelite Dilecto XX grade tubing and silk covered wire are used throughout. Supplied with bracket and screws for either panel or table mounting; flexible leads provided for connecting to switch points. Advantageously used in connection with De Forest Type S-600 Variable B Battery switch. Price complete with Bakelite knob and dial, $3.75.





Combination Rheostat and Potentiometer Type RP-500

Unusual conservation of panel space and ease of control is afforded by this combination, on one moulded base with double knob control, of our F-500 standard rheostat and our P-1 potentiometer. Made also as RP-600, combining our F-600 power rheostat with the P-1 potentiometer, on common Bakelite mounted base, with concentric two-knob control. Price of either combination instrument, $2.00.

Made with the precision characteristic of all De Forest parts.

156

PLAINTIFF'S EXHIBIT No. 181.
DeForest Catalogue B of 1919.

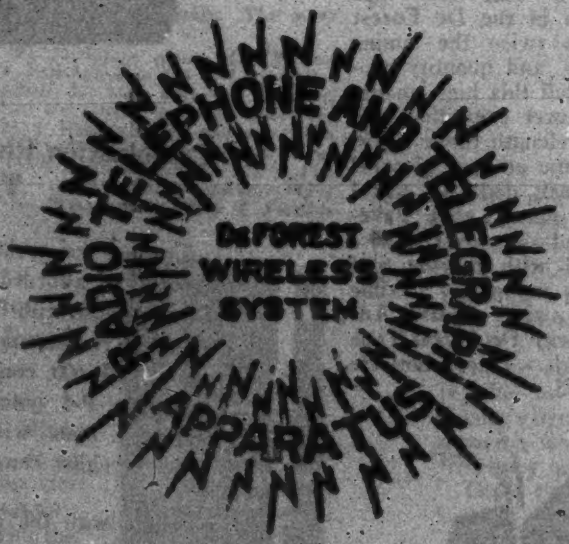
DE FOREST

181
Plaintiff's

POST-WAR MODELS

of

RADIO APPARATUS



CATALOG B

Manufactured by

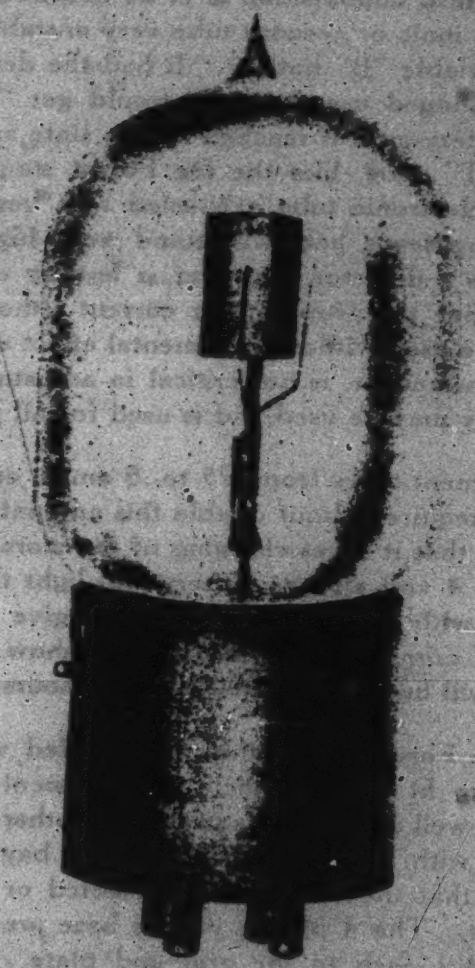
De Forest Radio Telephone & Telegraph Co.

1415 Sedgwick Avenue, New York

Cable Address: Radiotel, N. Y.

SEPTEMBER 1919

THE NEW DE FOREST "VT" AUDION



This tube is identical with the latest forms of tubes manufactured by the De Forest Radio Tel. & Tel. Co. for war work and is similar in shape to the VT-21 tube of which the De Forest Company made thousands for the Signal Corps during the war. In the United States its sale is restricted to amateurs and experimenters for reception only.

The tube consists of a highly evacuated vessel cylindrical, rather than bulbular, in shape enclosing the three elements, grid, plate and filament in the form of the old type T tubular De Forest tube with which amateurs are familiar. The plate is of nickle, cylindrical in shape and surrounds a helical grid also of nickle. The filament is a crimped tungsten wire passing through the center of the grid exactly as it did in the old style T type De Forest tube.

The chief difference between this tube and the type T tube of similar mechanical construction is in its evacuation. The old style type T was an ionic or gaseous tube very unstable in operation and requiring a variable "B" battery. It had the decided disadvantage that after continued use the tube would get "hard" and require more "B" battery until it reached such a state as to be inoperative. The new "VT" tube, like the De Forest standard tubes to-day, is purely an electronic tube exhausted to a very high vacuum, so that it is nongaseous and will stand very high plate potentials. When used as a detector, however, a battery of 20 to 40 volts is sufficient to give the proper plate current although voltages of 80 to 100 may be used without detrimental effect upon the tube. The "B" battery moreover, is not critical in adjustment and, therefore, a fixed battery may be used and is used for all practical work.

The filament takes from .75 to .8 amps. only, whereas the old type T tube required about double this amount. This is a decided advantage in that it saves charging of the storage batteries at short intervals. A 4 volt storage battery will light the filament, but a 6 volt battery with a control rheostat will give better results. The filament is of crimped tungsten and tests show that the majority of these tubes will burn from 1000 to 2000 hours.

The De Forest "VT" tube is provided with the standard 4-prong base to fit the receptacle on all recent types of De Forest apparatus as well as apparatus put out by other concerns. The base is provided with a pin which fits into a bayonet lock in the receptacle, so that the tube may be inserted or removed by merely a slight twist. The 4 prongs on the base are connected, 2 to the filament and 1 each to the grid and plate. These prongs mesh with springs in the bottom of the receptacle and in this way perfect connection is made to the receiving apparatus without the use of awkward flexible leads, binding posts, etc.

Amateurs are warned that the only tube available on the market at present is the De Forest "VT" tube above described. All other tubes advertising an outside plate or outside grid are humbugs sold to get around the De Forest patents and are absolutely worthless from an operative point of view.

De Forest "VT" Audion **Price $7.00 each**

INSTRUCTIONS FOR USING THE DE FOREST AUDION

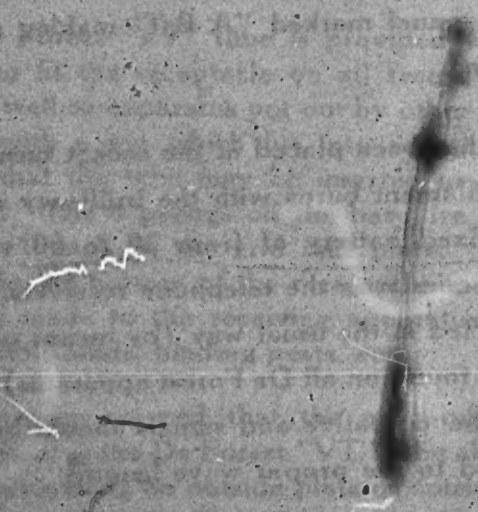
These instructions apply to the new type high vacuum tube such as was used by the U. S. Army and Navy and is at present being manufactured by the Moorehead Company exclusively for the De Forest Company under the latter's patents. The Marconi Company are sole distributors for us. The old type gaseous tube with the candelabra base can be used similarly, except that a variable "B" battery of from 20 to 50 volts is required. The gaseous type tubes are, however, no longer being manufactured.

The audion tube should not be inserted into its socket until the operator is definitely sure that the control rheostat is set at the point marked "Off" or with its full resistance in circuit.

A 6 volt storage battery should be connected to the binding posts on the audion panel marked "A Bat" making sure that the polarity is as indicated.

After the tube has been placed in the socket turn the rheostat up slowly until the filament burns with the brilliancy of a tungsten lamp. Connect a fixed battery of from 20 to 60 volts into the plate circuit and in series with the telephone receivers. If then the grid circuit is connected in the usual way (by means of the binding posts "RA"—"RE" found on all De Forest apparatus) to the tuner, the audion should be operative and signals should be received as the circuits are tuned to the proper wave lengths.

PLAINTIFF'S EXHIBIT No. 182.
DeForest Type-T Audion Tube.



De Forest "VT" Audion **Price $7.00 each**

183

Sterling RADIO EQUIPMENT

Vacuum Tube Reactivators

Home and Professional
Vacuum Tube Testers

"A" and "B" Battery Chargers

Full Range Audio Transformers
Radio Frequency Transformers

Pocket Ammeters, Voltmeters
and Voltammeters

Panel Ammeters, Voltmeters
and Milliammeters

Soft Tread Rheostats
Potentiometers

Wide Range Microcondensers

Manufactured by

THE STERLING MANUFACTURING CO.
2831-53 Prospect Avenue
Cleveland, Ohio, U. S. A.

Electrical Manufacturers since 1906

Form No. C6

PLAINTIFF'S EXHIBIT No. 183.
Circular of Sterling Reactivator.

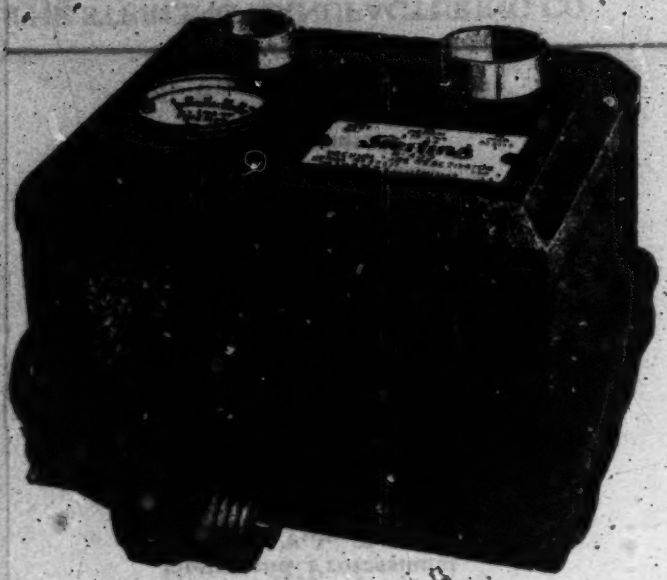
181

The Sterling No. R-403 Vacuum Tube Reactivator

For
UV-201-A
C-301-A
and
UV-199
C-299
Types of
Vacuum
Tubes

THE
EMISSION
METER

shows—



Size—6"x7½"x5" high.
Weight—4¾ lbs. net.
Portable, handle on back.
Black frostine finish.
Silver etched meter dial.
Rubber feet.
Nickel sockets for large and small tubes.
5' lamp cord with plug.
Meter Equipped.

Sterling

Whether a Tube Actually Needs Reactivation
Just How Much Its Amplification Has Been Improved By The Process.

LIST PRICES
For 110 Volt (A.C.) Current 50 or 60 cycle frequency— $12.50
For 110 Volt (A.C.) Current 25 or 40 cycle frequency— $14.00
West of the Rockies—Slightly Higher.

Manufactured by
The Sterling Manufacturing Company
2831-53 Prospect Ave., Cleveland, O., U. S. A.—Electrical Mfgr's. since 1906

Every User and Seller of Vacuum Tubes Needs This—

Sterling Meter Equipped Portable
TUBE REACTIVATOR

A Promoter of Good Reception
An Economizer of Tube Expense
A Tube Saver for the Set Owner
A Profit Maker for the Radio Dealer
A Time and Money Maker
for the Service Man

How to Get the Most Out of Your Radio Tubes—Most Economically

USERS of Radio sets are of two general classes—

—those who derive their pleasure from listening to continuously good radio, preferring not to concern themselves with the how and why of it.

—and those who delve into the technicalities of radio construction and find pleasure or profit in the results of their own handiwork.

Sooner or later, however, *all* who enjoy radio, whether layman or expert, will realize the importance of the results which can be obtained by renewing the life of vacuum tubes. And this is true because not only does the quality of radio reception depend upon the condition of tubes, but one of the heaviest items of a set's maintenance expense results from tube replacements.

The radio expert is already familiar with the simple process which renews the life of what is known as the thoriated filament types of vacuum tubes. This process is called Tube Reactivation. Filament reactivation of vacuum tubes is not a mystery beyond the layman's understanding, nor is it beyond his interest, because by tube reactivation he can be assured of getting the utmost in quality of reception and in length of service from his vacuum tubes, and at the same time save a large portion of his tube expense. These two advantages, therefore, should be well worth the few moments spent in learning how tubes can be quickly and thoroughly reactivated, and why the process can be repeated time after time.

What Are the Symptoms of Weakened Tubes?

The conditions which definitely indicate to the set owner that the tubes should be checked up immediately are those with which most set owners are already familiar, although they seldom understand the cause. Some of the most common difficulties are weak signals on distant stations, loss of volume on local stations, or general poor quality reception from all stations. Another indication of an impaired tube, or tubes, is found in the necessity of turning the filament current higher and higher in an effort to force the tubes to function as they originally did. This is an injurious practice, because it not only draws excessively on the A battery and pulls down the volume of the good tubes in the set, but the excessive filament voltage damages the tubes and speeds the hour when they become wholly inoperative.

It should be remembered that no radio set is better than its weakest tube. And no set will long continue to operate efficiently nor economically unless all of its tubes are given frequent tests, and reactivated when the evidences of deterioration appear. The process of reactivation or renewing the life of a vacuum tube filament is more simple than charging an A battery. Less time is required to do it. The result is more lasting, the cost much less.

Reactivate Tubes of the Thoriated Filament Types

The tubes found in most sets are of two types known as UV-201A and C-301A (large tubes) and UV-199 and C-299 (peanut tubes). In these tubes are three elements—the plate, the grid and the filament. Each of these elements has a very definite work to do, but most important is that of the filament. It is upon the *condition* of the filament that the functioning of the other elements depend. And what is more important, this condition largely controls the quality of reception that can be had from a receiving set.

Every time a tube is used the filament performs its work less efficiently than the time before. Indeed, from the very moment of its first use, the filament goes through a continuous process of change and deterioration until finally the tube becomes lifeless and fails to amplify. This falling off in tube efficiency may be abrupt under certain conditions, but usually it is so gradual that the user either ignores much time in looking elsewhere for his difficulties or discards his tubes altogether. *Nine out of ten of these discarded tubes could have been made to give many more months of good service by the process of reactivation.*

So, by a better understanding of the importance of the filament, just how it functions, and a knowledge of the method now offered to renew its life, home operators of sets may have good reception continuously and at a fraction of a tube cost heretofore necessary.

What Actually Happens to the Filament?

First, let it be understood that for a vacuum tube to operate at all its filament must give off electrons. This is technically known as "filament emission". As the filament emission becomes less and less the tube's ability to amplify diminishes and the quality of reception falls off in proportion. New tubes should possess high filament emission, but this constantly decreases according to the amount of use or abuse to which they are subjected. In the UV-201A, C-301A, UV-199 and C-299 types of tubes, the filament is made from a special tungsten wire in which a metal known as thorium has been combined. The filament is active only when there is a layer or coating of this thorium on the surface, and, as previously stated, the condition of this coating governs the amount of filament emission. Operating a set at too high filament voltage will destroy the coating quickly and result in rapid deterioration of the tubes; and even at normal voltage the filament usually deteriorates through continuous use. In either case, poor reception will eventually result.

When poor reception becomes apparent, too many set owners—those who are unfamiliar with the process of reactivating the thorium coating—discard one or more tubes because they have been long in use. Other owners, not equipped to properly test tubes, replace the tubes believing the discarded ones must be worthless. *Nothing could be further from the truth.*

A thoriated filament tube should not be declared "dead" simply because it fails to give the required amount of amplification. So long as the thoriated filament tube will burn, reactivation seldom fails to restore it. By the Sterling method of controlling the process of reactivation, the renewal of such tubes to their original amplification values may be made a certainty, and may be repeated over and over.

How It Is Possible to Make Tubes Come Back to Life

The thoriated filament tube becomes weak or lifeless as the thorium disappears from the surface of its filament. It is obvious that if the coating of thorium could be restored to the surface of the filament the tube would again be capable of amplification. This seemingly impossible result can be easily accomplished with the proper equipment. Inside the filament there remains a considerable supply of thorium and this is what makes reoperation possible, not only once, but repeatedly.

By the use of a simple and inexpensive electrical device, the STERLING REACTIVATOR, it is found that by burning the filament for a very short time at a high temperature followed by a lower temperature for a longer period, the thorium molecules are brought to the surface of the filament where a new thorium layer is formed. Thus, the amplifying ability of a seemingly exhausted tube is restored to its original strength. Some tubes have been successfully treated as many as seventy-five times with the Sterling Reactivator.

The Sterling Metered Instrument Takes the Guesswork Out of Tube Reactivation

Unless some means is provided for first actually testing a tube's emission, also for retesting to determine its increase in emission during and after a treatment, then tube reactivation becomes an uncertain process.

(1) When does a tube need reactivation?
(2) Is emission improving during treatment?
(3) What is its filament emission afterward?

Because of the importance of these three questions, the Sterling is provided with a FILAMENT EMISSION METER which removes all doubt as to what the reactivator accomplishes. For example, if, when a UV-201A tube is inserted in the Sterling instrument, the emission meter shows a reading lower than 20, reactivation is necessary. This test can be made instantly simply by moving a lever. Very often tubes will be found in which the filaments are slow to respond to reactivation, yet are capable of much higher emission than will be shown after one short treatment. For example, if the meter indicates only 30 to 40 after the tube has been in the instrument for the prescribed time, the "Low" or "Test" voltage generally results in increasing the emission. Without the meter in the instrument for checking the emission, the need of a second treatment would many times not be apparent, and even if it were tried the user would not be *certain* that he had increased the tube's amplification ability in the least.

Moreover, without an emission meter it is impossible to match tubes—to group them at approximately equal filament emission. In fact, without a meter the determination of the relative filament emission of tubes, to obtain the best reception from a set, is no more than a matter of guess-work. With the Sterling metered instrument results are *observed, controlled* and known to be *definite.*

Reactivate Tubes Only When a Filament Emission Test Shows They Need It

Reactivating tubes at regular periods without first testing them to determine the amount of filament emission present, is *not* recommended. Unless the filament needs reactivation, the process has the tendency to shorten the useful life of the tube. It is good practice, however, to check emission frequently to insure good amplification, also to be certain that one or more tubes are not being operated at too low efficiency, and that tubes are not being blamed for other possible defects in the receiving set.

The filament emission meter used in the Sterling instrument is a unique feature, essential to intelligent treatment of tubes and to accurate results. By its use, treatment of most thoriated filament tubes may be repeated many times with the result that the tubes will give their original amplification after being reactivated. Complete Instructions for operating are attached to the bottom of each instrument.

Sterling R-403 Tube Reactivator is just as essential to the proper care and use of vacuum tubes as is the battery charger to the battery. It is built with the same care that has for more than fifteen years made every Sterling electrical product worthy of its name.

In case your Dealer can't supply a "Sterling" write the factory direct.

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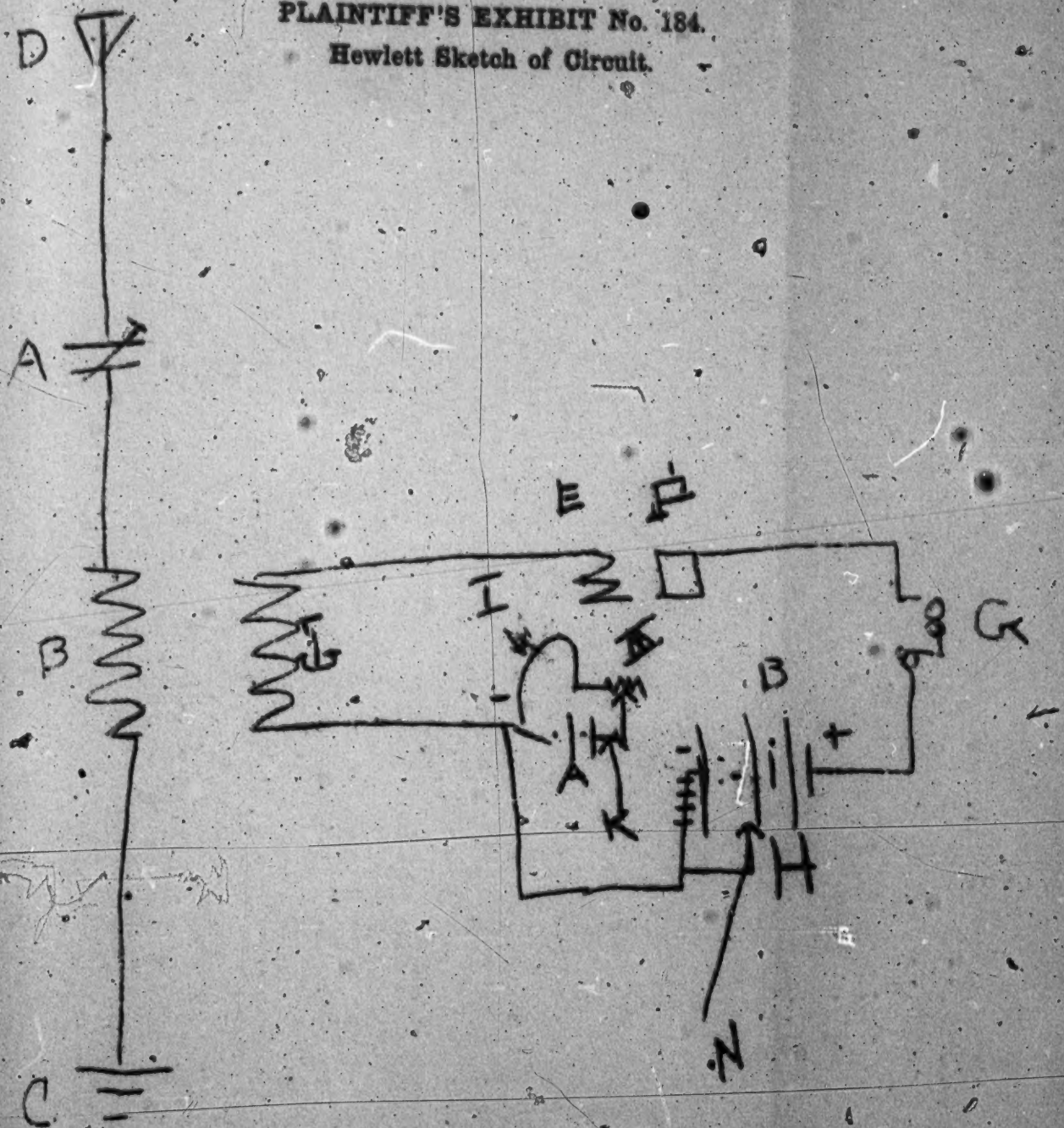
PLAINTIFF'S EXHIBIT No. 184.
Hewlett Sketch of Circuit.



PLAINTIFF'S EXHIBIT No. 185.
Letter and Data Sheets Furnished by Witness Kelly.

October 28, 1926

Dear Mr. Hogan:

In the preparation of this data two slight errors were detected. The pressure for Exhibit 32 should be about one-half that previously given. The actual slope of the lower line for 9.111 should be a little steeper.

These matters will be alluded to (so I understand) in my further examination this morning.

M. J. KELLY.

8 sheets of data herewith.

Plaintiff's Exhibit No. 185

Type 7510 with N_2

	Pr. .002 microns	.02 microns	.64 microns	1.2 microns
E_B	I_B	I_B	I_B	I_B
20	.30	.30	.30	.30
30	.90	.90	1.10	1.20
40	1.95	1.94	2.30	2.60
50	3.15	3.15	3.90	4.40
60	4.80	4.81	5.80	6.50
70	6.50	6.48	8.10	9.40
80	8.60	8.60	10.60	12.70
90	10.60	10.60	13.30	15.80
100	12.80	12.82	16.30	20.10
110	15.25	15.22	19.20	24.0
120	17.65	17.67	22.30	28.4

All I_B in milliamperes.

Audion 64-91

Ex. 80

E_B	I_B microamps. $E_C = 0$
20	7.5
30	15.0
40	25.0
50	43.
60	65
70	95
80	135
90	185
100	225
110	265
120	315.

Plaintiff's Exhibit No. 185

Tube No. 9899

Arnold 105 approx.

E_B	I_B in microamperes. $E_C = 0$
20	1.8
30	12.4
40	36.0
50	74.8
60	128.4
70	196.4
80	277.
90	377.
100	487
110	616
120	756
130	904

102-D

$E_C = 0$

E_B	I_B
10	.001
20	.010
30	.034
40	.076
50	.146
60	.250
70	.370
80	.500
90	.664
100	.848
110	1.040
120	1.260
130	1.490

Milliamperes.

Ex. 32 Tube 105

E_B	I_B
20	—
30	0.5
40	5.5
50	16.0
60	32.0
70	57.0
80	92.5
90	137.
100	191
110	256
120	332
130	406.

Microampgres.

Arnold Ex. 30

E_B — 10, E_C + 100 volts from negative end of fil.

10^{-7} amps.

	I_A	I_C	I_{B_1}	I_{B_2} Leak.	$I_{B_1} - I_{B_2}$	
	1.10 A.	.65 ma.	3.12 × 10^{-7} amp.	2.61	.51	Pr
	1.13	1.10	3.54	2.48	1.06	micro
	1.17	1.60	4.13	2.69	1.44	.0144
2 min.	1.18	1.60	4.17	2.69	1.48	.0148
4 min.	1.20	1.60	4.19	2.78	1.41	.0141
8 min.	1.17	1.60	4.16	2.70	1.46	.0146

Load Test Plate Pos. Grid Neg.

I_A 1.15 amps. × 10^{-7} amps.

I_B	E_B	E_C	I_{C_1}	I_{C_2}	$I_C = I_{C_1} - I_{C_2}$	
.3 na.	150	— 0.07	5.20	3.65	Gas. 1.55	
thruout.	160	2.2	6.10	4.15	1.95	
	180	4.4	6.85	4.70	2.15	
2 min.			7.00	4.80	2.20	
4 min			7.05	4.90	2.15	
6 min			7.10	5.00	2.10	

Arnold Ex. 32

Pr in microns $= K_3 \times I_B$ (in microamps).

Ionizat— Meas. Grid Pora, Plate Neg. See separate page.

$E_C = +100$ $E_B = -10 \times 10^{-7}$ amps.

	I_A	I_C	I_{B_1}	I_{B_2} Leak	$I_{B_1} - I_{B_2}$	Pr Micas u
	1.26	.92	.48	.19	.29	—
	1.34	2.27	.92	.19	.73	.0051
2 min.	1.34	2.30	.98	.23	.75	— .0053
5 min.	1.36	2.3	1.06	.27	.79	— .0055
10 min.	1.36	2.31	1.04	.28	.76	— .0053

I_A—Approx const. Load Test — $\times 10^{-7}$ amp.

I_B	E_B	E_C	I_{C_1}	I_{C_2} Leak	I_C Gas.
.4 m.a.	130	— .37	1.17	.18	.99
.4 m.a.	140	— .74	1.32	.21	1.11
	150	—1.10	1.42	.25	1.17
same throughout	160	—1.47	1.54	.26	1.28
	170	—1.80	1.65	.33	1.32
	180	—2.20	1.72	.36	1.36
2 min.	180	—2.25	1.80	.40	1.40
6 min.	180	—2.20	1.89	.46	1.43
0 min.	180	—2.10	1.77	.39	1.38
4 min.	180	—2.20	1.80	.33	1.47

$P = K\ I_{Gas}$

Thruout P in microns

K_G in microamperes.

K_1 for std manometer for 20 milamp. at E_C 100 $E_B - 10$ is .005.

K_2 for $\times -9450 - \times 9452$ for 20 milap at E_C 100 $E_B - 10$ is .010 by comparison with standard for range of pressures.

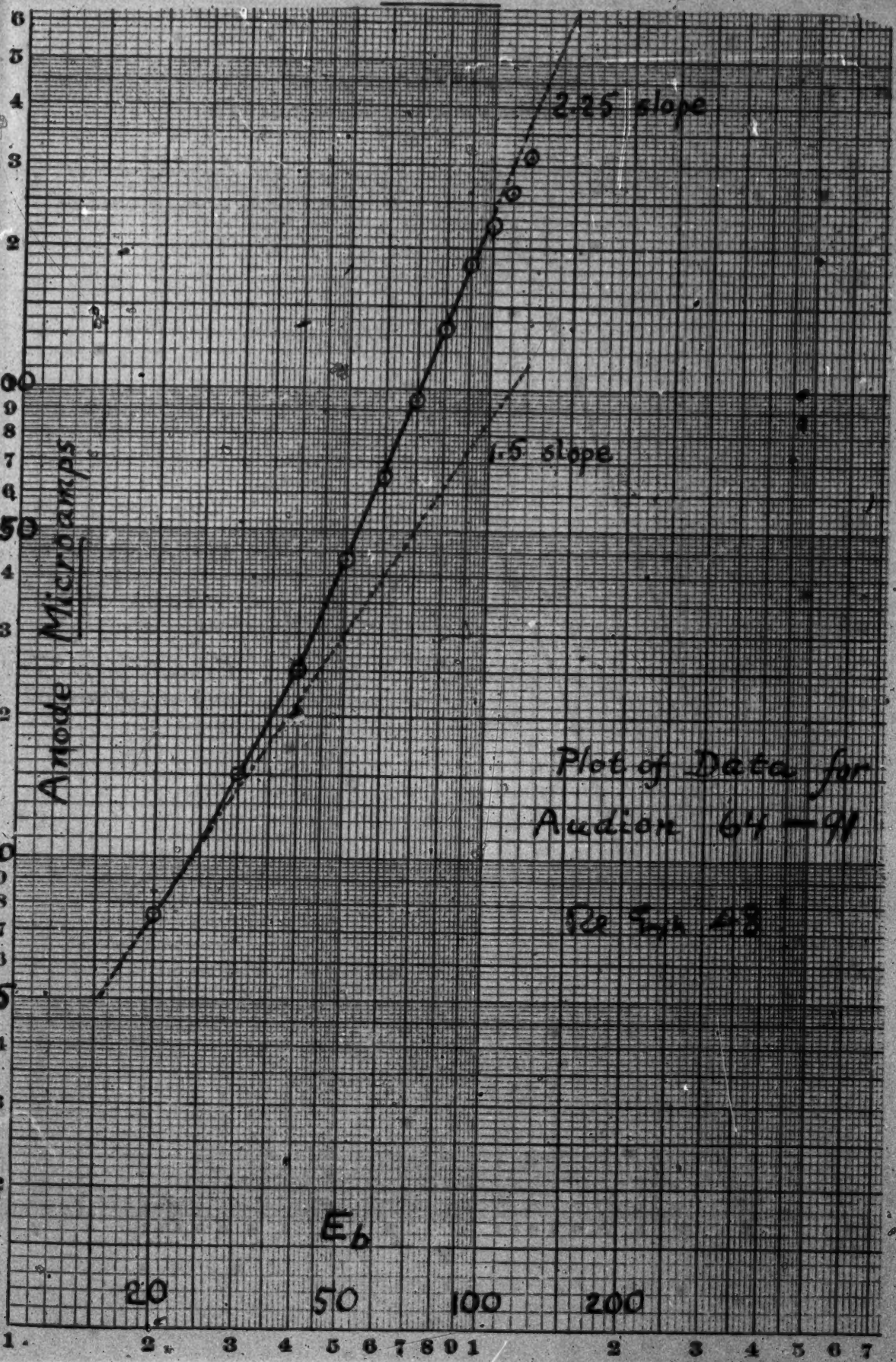
K_3 for $I_B = 2.3$ milamperes $= 0.07$.

K_4 " $I_B = 1.6$ " " $= 0.10$

K_3 and K_4 determined by keeping for fixed and varying electric current to grid over range of values including 1.6, 2.3 and 20 m.a.

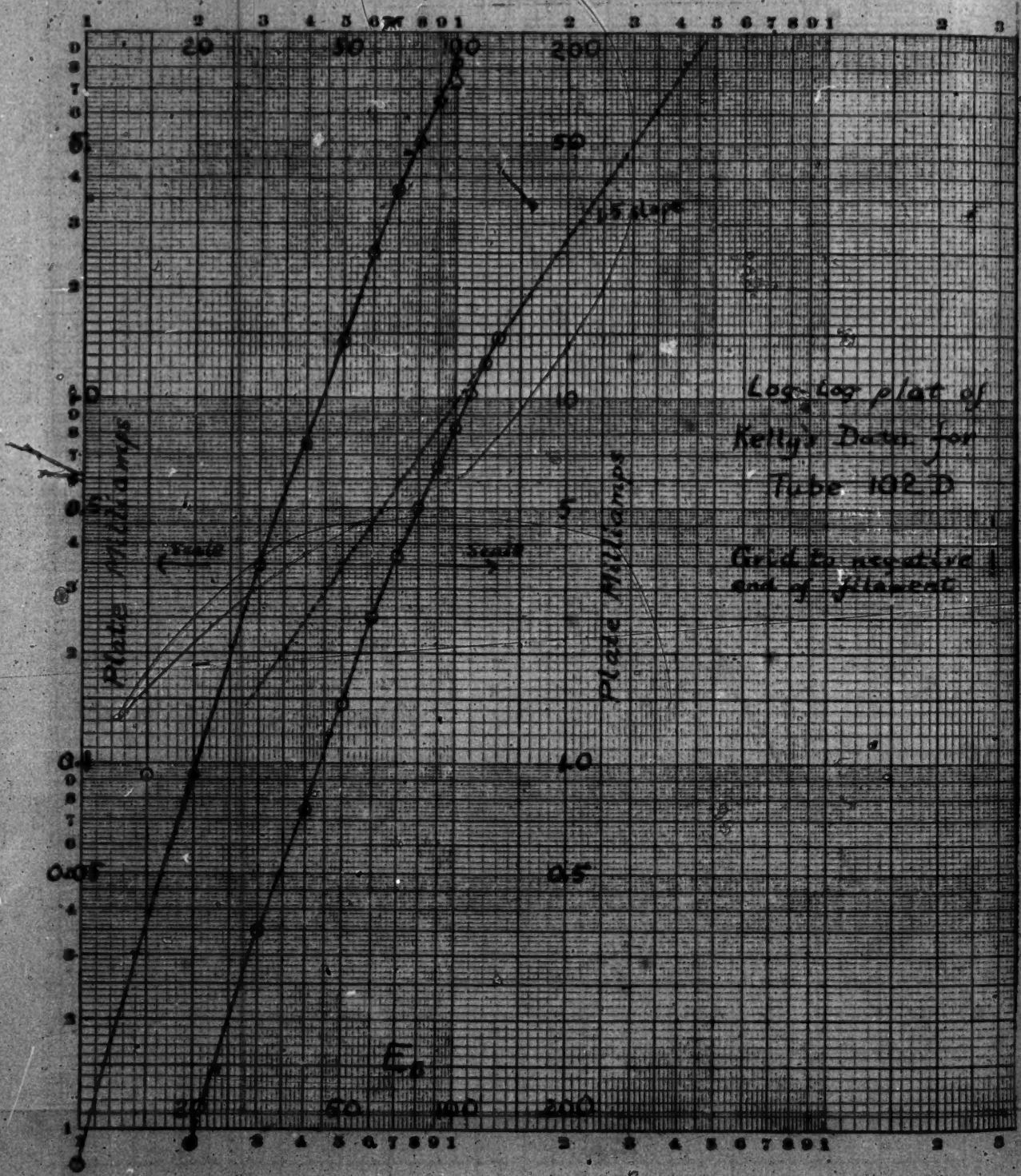
PLAINTIFF'S EXHIBIT No. 186.

Hogan Logarithmic Plot of Audion 64-91.



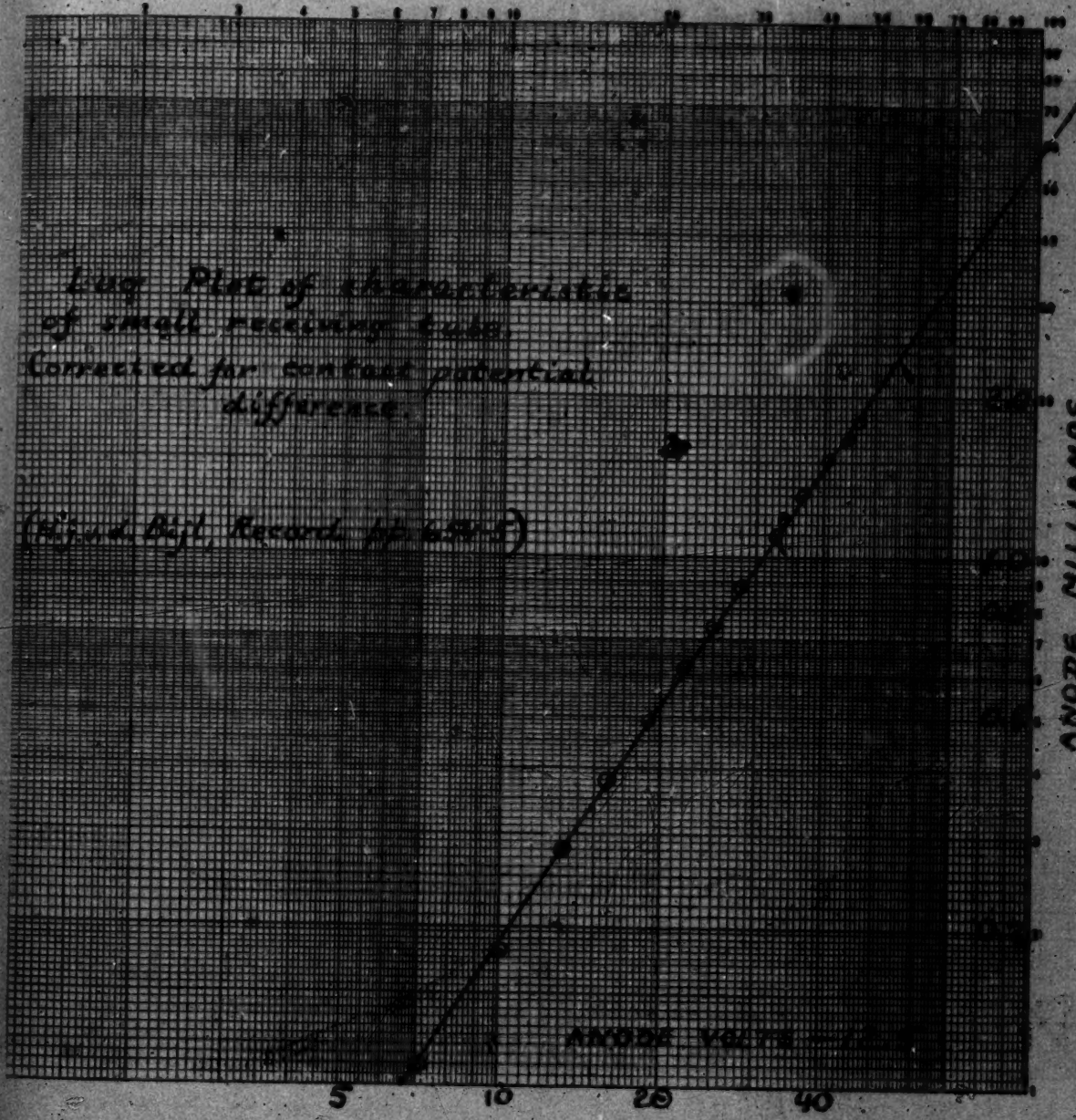
PLAINTIFF'S EXHIBIT No. 187.

Hogan Logarithmic Plot of Kelly Data for Tube 102-D.



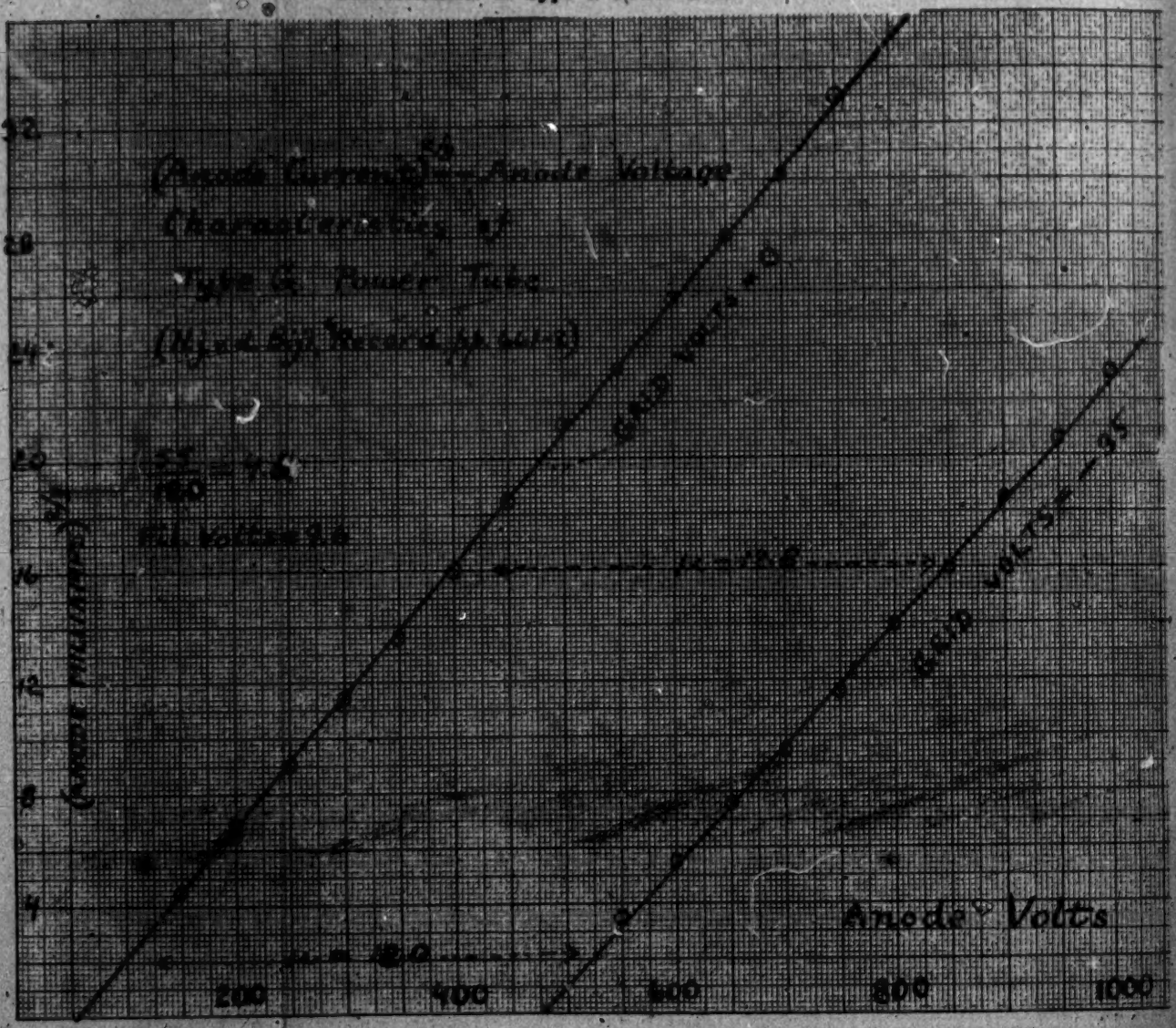
PLAINTIFF'S EXHIBIT No. 188.

Hogan Logarithmic Plot of Characteristics of Small Receiving Tube Corrected for Contact Differential.



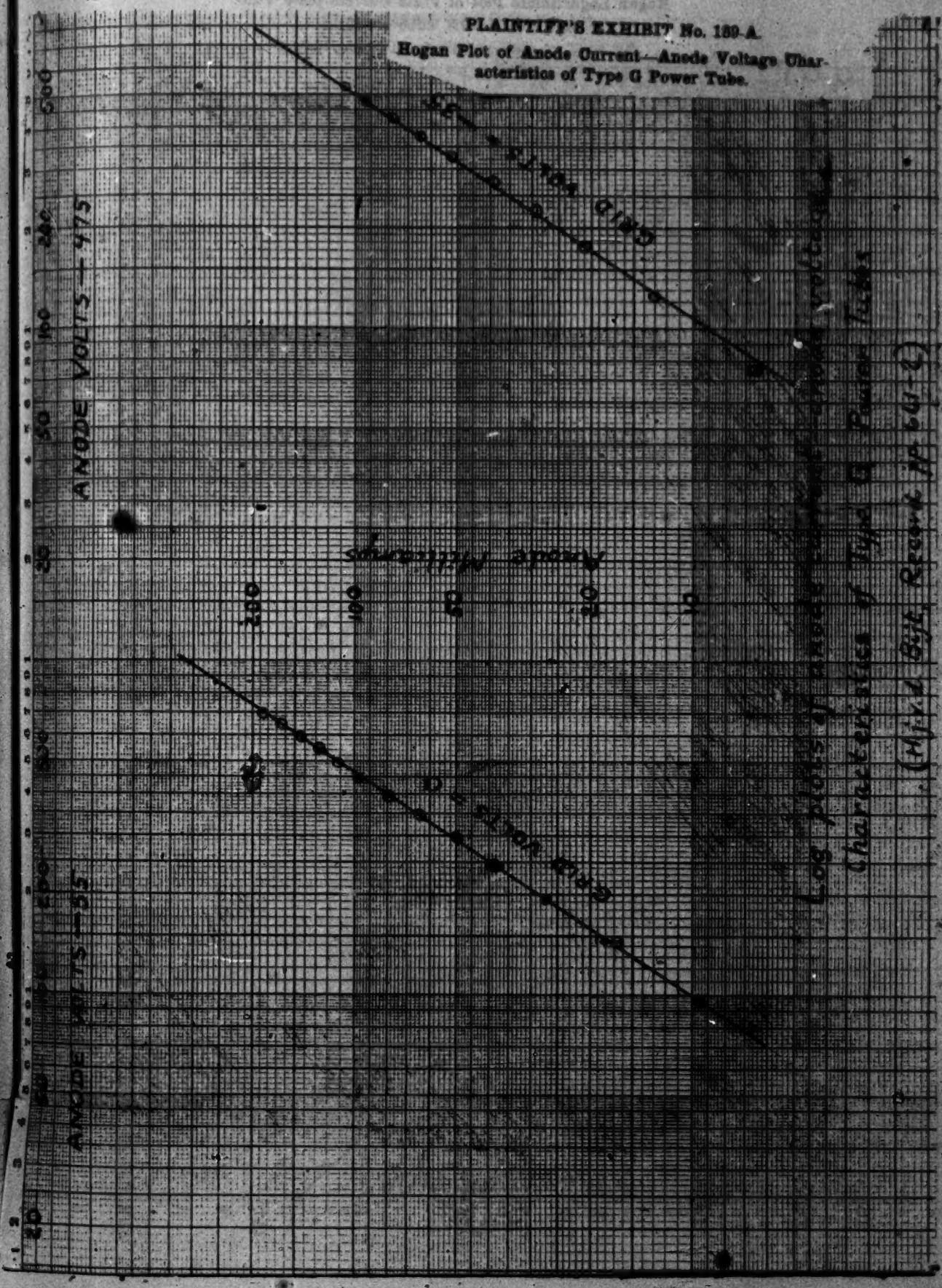
PLAINTIFF'S EXHIBIT No. 189.

Hogar Plot (Anode Current) 2/3—Anode Voltage Characteristics of Type G Power Tube.



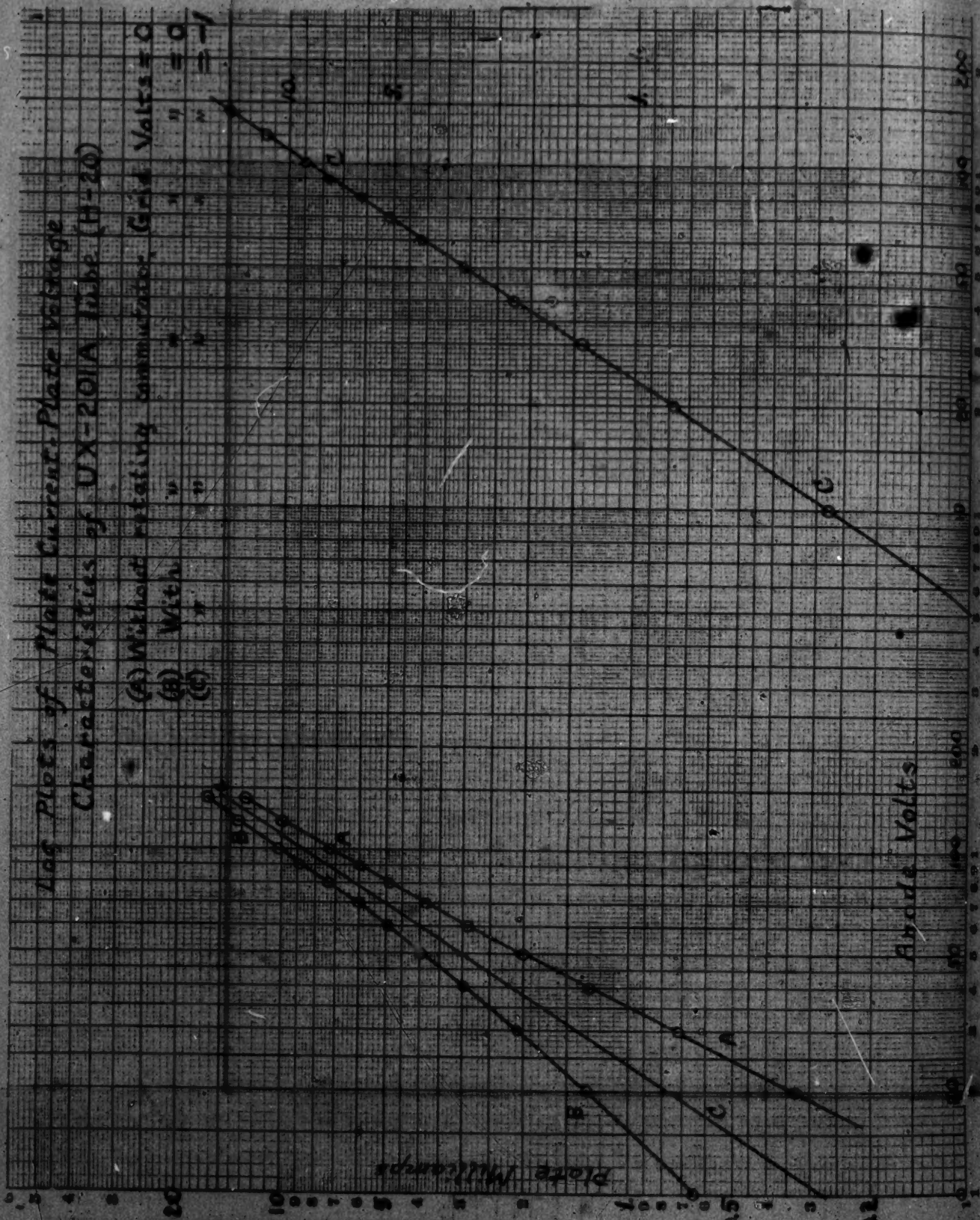
PLAINTIFF'S EXHIBIT No. 139-A.

Hogan Plot of Anode Current—Anode Voltage Characteristics of Type G Power Tube.



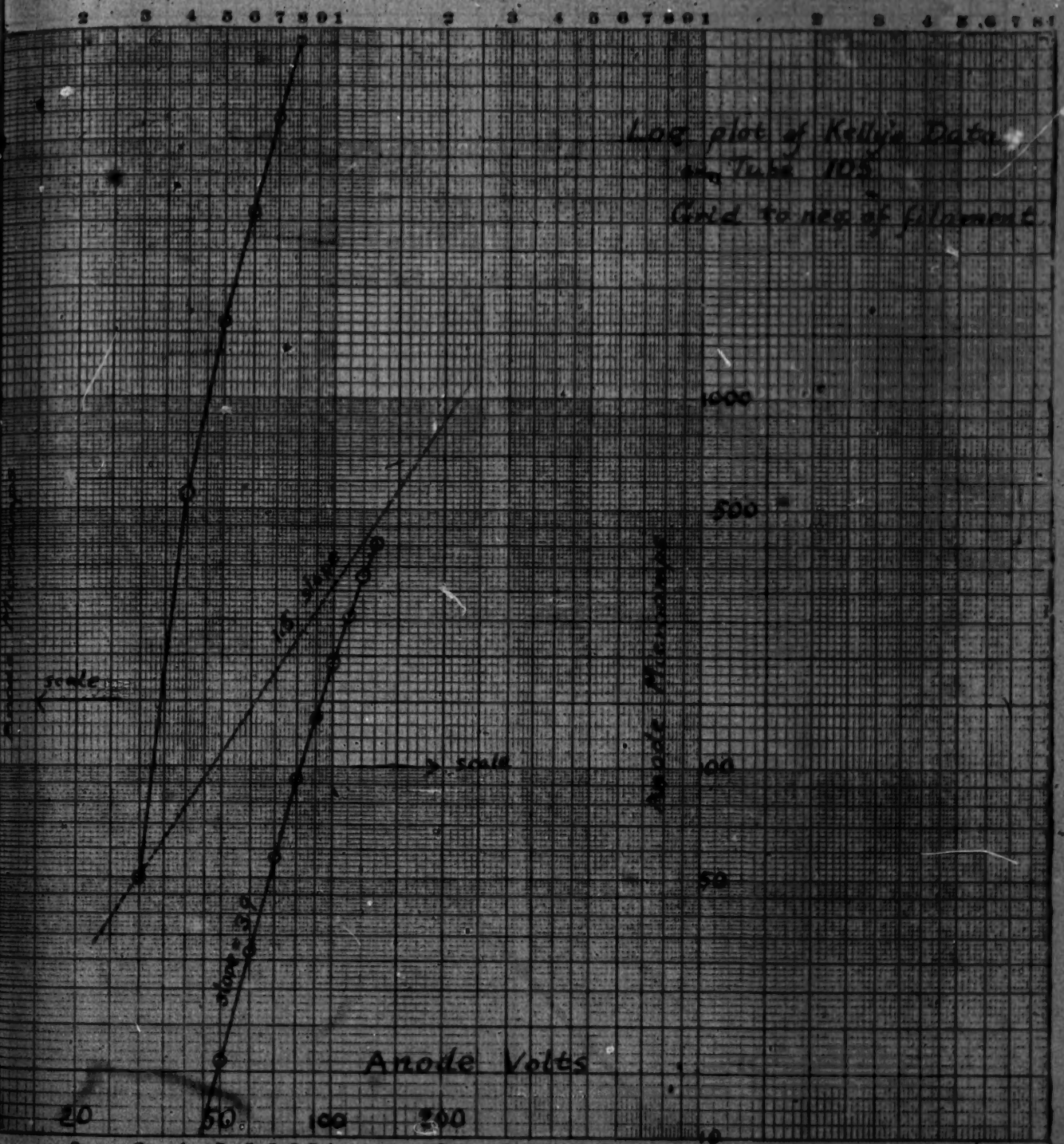
PLAINTIFF'S EXHIBIT No. 190.

Hogan Logarithmic Plot of Plate Current-plate Voltage of UX-201A Tube (H-20).



PLAINTIFF'S EXHIBIT No. 191.

Logarithmic Plot of Kelly's Data on Tube 105.

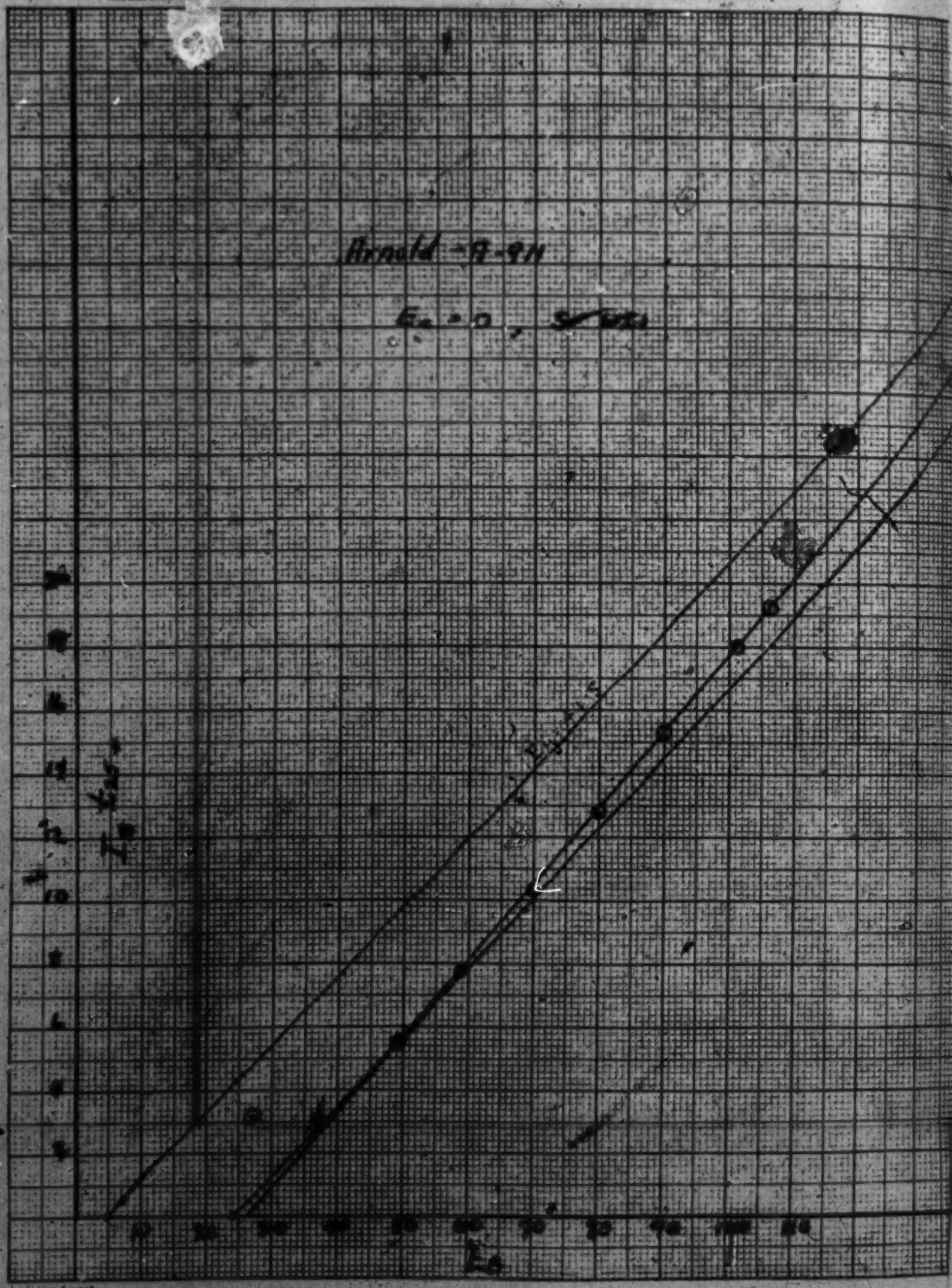


PLAINTIFF'S EXHIBIT No. 192.

Hogan Copy of Defendant's Exhibit 54-A, with Additional Lines Thereon.

BELL TELEPHONE LABORATORIES

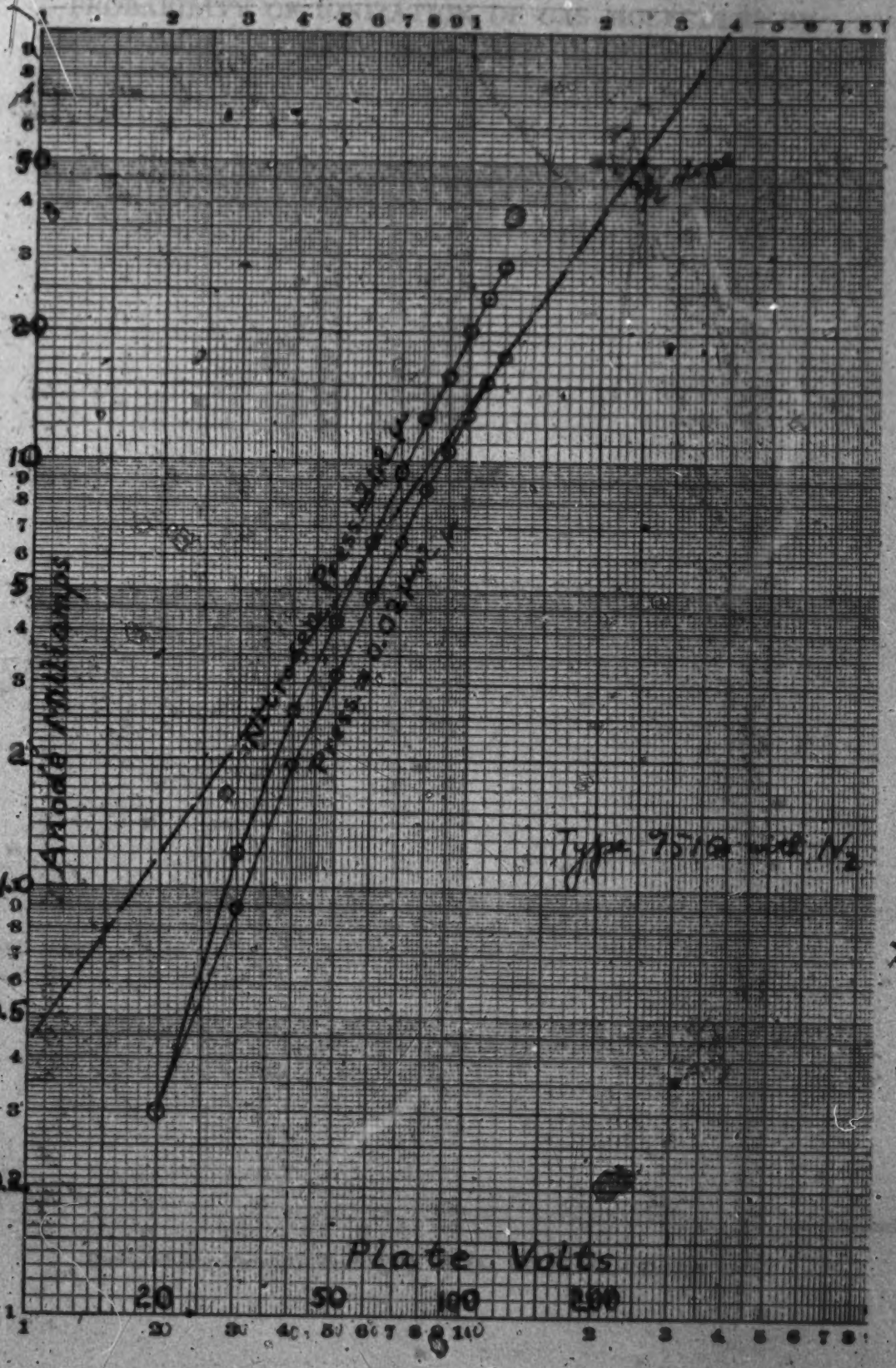
Sketch No. ES



183

PLAINTIFF'S EXHIBIT No. 183.

Hogan Logarithmic Plot of Type 7510 with Nitrogen.



PLAINTIFF'S EXHIBIT No. 194.

PROBABILITY OF IONIZATION OF GAS MOLECULES BY ELECTRON IMPACTS

BY

K. T. COMPTON AND C. C. VAN VOORHIS

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PROBABILITY OF IONIZATION OF GAS MOLECULES BY ELECTRON IMPACTS

By K. T. Compton and C. C. Van Voorhis

Abstract

Ionization in various gases by electrons of energy 0-325 volts.—Electrons from a hot filament were projected through an ionization chamber B containing gas at low pressure (.001 to .005 mm) and into a trap. Positive ions produced in B were collected on fine wires arranged in the form of a squirrel cage C and maintained at a potential lower than B by an amount V_r. Corrections were made for the facts (1) that the wires C lowered the potential at the center of B and hence retarded the electrons passing through B by a maximum amount of $0.4\times V_r$, and (2) that if V_r was numerically less in value than the accelerating potential V_a, some primary electrons reached C. The pressures were measured with a McLeod gauge to 1 percent and were corrected for the heating effect of the filament, which was determined by using the apparatus as an ionization manometer to be about 26°. The resulting curves for N, the number of ions per cm path produced by an electron moving through a gas at 1 mm pressure, are believed correct within a few percent. In agreement with previous results of Hughes and Klein and others, the curves each rise to a maximum. The maximum values found and the corresponding voltages are as follows:

	H_2	He	Ne	A	N_2	Hg	HCl
N(max):	3.55	1.65	3.2	10.33	9.96	19.44	17.3
V(max):	145	210	340	140	175	135	130
P(max):	0.29	.209	.254	.466	.423	.239	.558

The values for P(max), the corresponding probability that a collision will result in ionization of the hit molecule, were computed from N(max) assuming the kinetic theory values for electronic mean free paths. These results are compared with previous experimental values. Ionization was found to begin at the ionizing potential in each case, except that with N_2 weak ionization was observed at 10 volts. This may possibly be associated with the presence of traces of active nitrogen.

TOWNSEND'S original theory of ionization by collision[1] assumed that ionization of a gas molecule occurs whenever it is struck by an electron whose speed exceeds the minimum ionizing speed, but this theory led to values of the minimum ionizing speed which were considerably in error. Bergen Davis[2] and one of the writers[3] modified Townsend's theory by assuming that the relation between the energy V of an electron at impact and the probability P that ionization of the molecule results from the impact is given by $P=(V-V_i)/V$ when $V>V_i$ and $P=0$ when

[1] Townsend, "The Ionization of Gases by Collision."

[2] Bergen Davis, Phys. Rev. 24, 93 (1907).

[3] K. T. Compton, Phys. Rev. 7, pp. 489, 501, 509 (1916); Compton and Benade, Phys. Rev. 11, 234 (1918).

$V < V_i$. This assumption led to calculated values of the minimum ionizing energy V_i which agreed better with the true values than did Townsend's original theory, but which were still incorrect. The recent advances in the study of various types of electrical discharge through gases, and especially the development of Langmuir's[4] new method for determining the distribution of velocities of the electrons in an ionized gas, have emphasized the importance of accurate knowledge of the values of the probability P of ionization by electron impacts at various speeds and in various gases.

The first experimental observations of this sort were made by Lenard[5] and were extended under his guidance by Kossel[6] and Mayer.[7] These investigators found that the probability of ionization is zero for impact energies up to the minimum ionizing potential, then increases to a maximum of less than 0.5 at impact energies of about 150 volts, followed by a decrease as the energy is further increased up to 1000 volts.

The present investigation was designed to introduce a number of refinements in technique, so as to permit the maximum possible accuracy of the observations. Shortly after we had begun, Hughes and Klein[8] published results of a research on the same problem, in which a considerable number of gases was tested over a large range of electron impact energies. In general features and in order of magnitude our present results agree with the findings of these and of the earlier investigators. We believe, however, that the present method permits greater accuracy of observation and reliability of interpretation than the methods previously used, so that we felt justified in continuing the work to its present conclusion.

The general procedure in such work is to accelerate electrons from a photo-electric or thermionic source and project them into a region in which the products of ionization are collected by a subsidiary system of electrodes. Besides obvious precautions of accuracy, calibration, gas purity, etc., there are several inherent difficulties encountered in endeavoring to measure the ionization per electron per unit path through the gas. The first of these is due to the fact that the electrode system which collects the products of ionization is subject also to charge arising from photo-electric action on the electrodes by radiation excited by electron impacts in the gas. The second difficulty is due to the necessity of apply-

[4] Langmuir, General Electric Review, 26, 731 (1924); Langmuir and Mott-Smith ibid. 27, pp. 444, 538 (1924).

[5] Lenard, Ann. der Phys. 12, 474 (1903); 15, 485 (1904).

[6] Kossel, Ann. der Phys. 37, 393 (1912).

[7] Mayer, Ann. der Phys. 45, 1 (1914).

[8] Hughes and Klein, Phys. Rev. 23, pp. 111, 450 (1924).

ing a field in the region between the collecting electrodes in order to draw to them the products of ionization and to prevent any of the primary ionizing electrons from reaching these electrodes. Because of this field, the primary electrons do not pass through the gas with a constant speed, but with speeds which vary from that with which they are projected into the ionizing region down to much smaller values (down to zero in the experiments of Hughes and Klein). It is, therefore, impossible to say to just what energy of impact the observed ionization should be ascribed, and it is necessary to compute the desired result by setting up an integral equation to represent the observations and to solve it by differentiating the experimental curve. To the above difficulties might be added a third source of error which arises from any ionization of a cumulative type or from more than one impact by the same primary electron.

In the present work we have eliminated the first and third of these difficulties and reduced the second so that the value for the ionization per electron per centimeter path is set experimentally within rather narrow limits and may be computed within these limits with but a small probable error.

Apparatus and its Use

The apparatus employed is shown in Fig. 1. The filament F consisted of a few turns of 10 mil (.25 mm) molybdenum wire, in front of which was placed a focusing ring connected to the negative terminal. The narrow tube T through the bottom of the shielding box served to direct a narrow beam of electrons into the middle region of the chamber B. The positive ions formed in B were attracted to the collector C, which consisted of five 20 mil wires supported at each end by a ring of the same sized wire. The use of small wires for collecting the positive ions had the triple advantage of reducing to an inappreciable value the photo-electric current from this electrode, of reducing the chance that primary electrons which might be scattered in the gas would reach this electrode, and of reducing the effect on the velocity of the primary electrons due to the collecting field V_c. The ion trap S served to catch the electrons after passing through B, and also any positive ions produced after passing through the gauze at the bottom of B. The chamber B was 2.8 cm long and about 3 cm in diameter. All metal parts were made of nickel except the filament, and were freed from gas by heating in vacuo to a red heat by high frequency induction currents.

The electrical connections used in making the measurements are shown in Fig. 2. The variable accelerating voltage was measured by a voltmeter V_a, while G_- and G_+ measured, respectively, the electron

current I_- into the chamber B and the positive ion current I_+ resulting from ionization by the electrons passing through the gas in this chamber. We thought, when beginning the investigation, that a magnetic field produced by a current through a coil wound around the glass jacket and

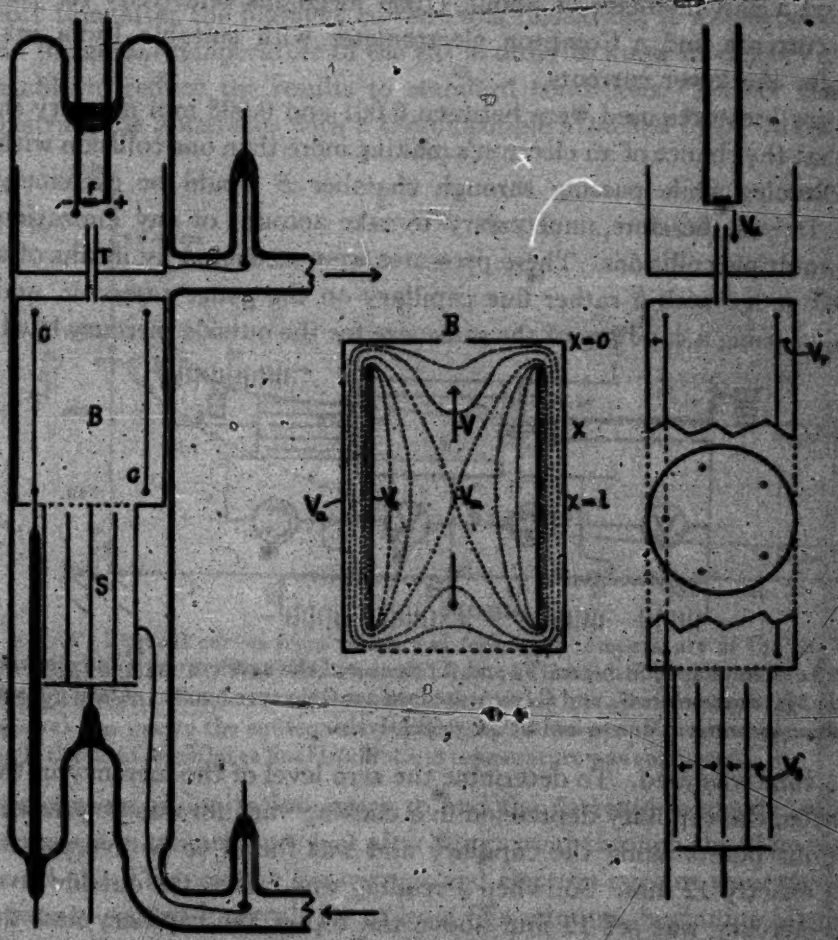


Fig. 1. Electrons from the filament F were projected through the tube T into the ionization chamber B in which the products of ionization were collected by a "squirrel cage" arrangement of wires C. The non-colliding electrons passed into the ion trap S. The dotted curves represent equipotential surfaces, with an axial point of minimum potential V_m, when the potentials of B and C are V_a and V_c respectively, with respect to the filament.

coaxial with the chamber B would prevent electrons from reaching the collector C and thus permit us to use so small a collecting field as not appreciably to affect the speed of the primary electrons passing through the chamber. When this plan was tried, however, it was found that the ratio of I_+ to I_- for any given pressure was very irregular, being subject to small variations in the magnetic field, and that these irregularities

could be shifted from lower to higher voltages by increasing the magnetic field. Not succeeding in explaining or eliminating this effect of the magnetic field, we abandoned its use and applied a retarding voltage V_r to the collector C to prevent electrons from reaching it. A galvanometer with a sensitivity of about 300 megohms was used as G_-, while for G_+ were employed a galvanometer of about 11000 megohms sensitivity for the higher currents and a Compton electrometer with suitable India ink shunts for the lower currents.

The gas pressures used were between 0.001 and 0.005 mm mercury in order that the chance of an electron's making more than one collision with gas molecules while passing through chamber B would be extremely small. It was, therefore, unnecessary to take account of any ionization due to multiple collisions. These pressures were measured by means of a McLeod gauge with a rather fine capillary on the gauge reservoir, and instead of using a capillary of the same size for the outside mercury level,

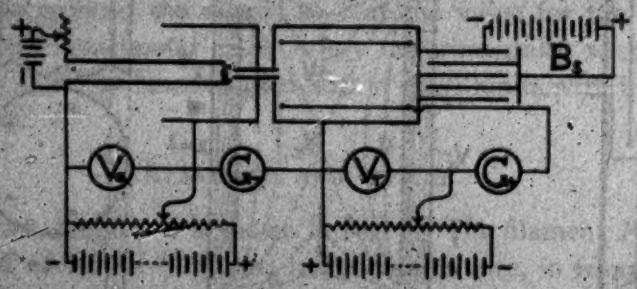


Fig. 2. Circuits. Voltmeters V_a and V_c measured the accelerating and collecting fields, and galvanometers G_- and G_+ measured the total electron current entering B and the positive ion current due to ionization, respectively.

a 1 cm tube was used. To determine the zero level of the mercury in the 1 cm tube, the capillary depression in a clicking vacuum was determined at various points along the capillary and was found to be everywhere almost exactly 12 mm. So, when a reading was taken, the outside level of the mercury was set 12 mm above the top of the capillary and the pressure read off the calibration curve as usual. The capillary tube was always tapped with a pencil while the mercury was coming to equilibrium in the tubes, to avoid any error due to the adhesion of the mercury to the walls. Also, parallax was avoided by observing the level of the mercury in the capillary through a lens mounted at the end of one edge of a small square. With these refinements the readings of the pressures varied less than 1 percent for different settings on the same pressure. A further check on the accuracy of the pressure readings was made occasionally by finding the product of the length of the gas-filled capillary times the difference in level of the mercury columns (the 12 mm capillary depression being de-

ducted of course) for different levels of the mercury in the capillary. This check was used whenever there seemed to be any pronounced sticking of the mercury in the capillary near the level used in the regular method of reading.

Determination of gas temperature. Since the chamber B became warm a short time after the filament current was turned on, it was necessary to find the actual temperature of the gas in order to know its density and to be able to reduce the results to standard conditions. Rather than reconstruct the apparatus with a thermocouple attached to B, we used the

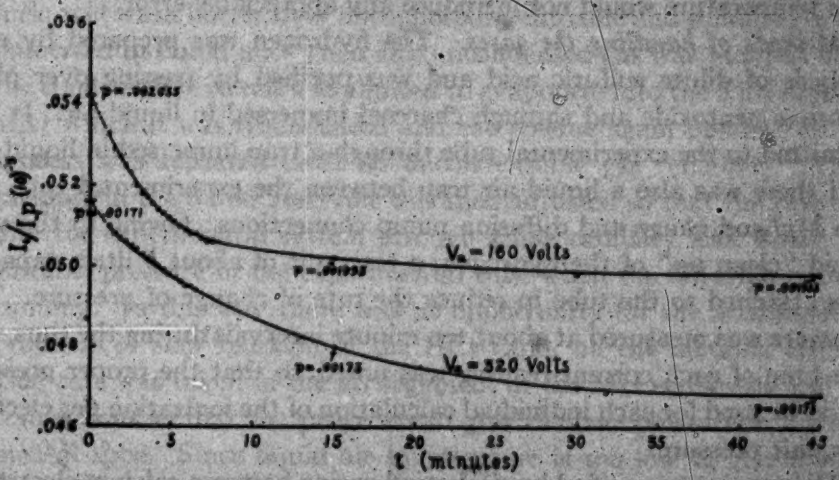


Fig. 3. Typical curves from which was found the temperature of the gas in the ionization chamber B. Time was measured from the instant of turning on the filament heating current. The decrease in ordinate (ionization per electron per 0.001 mm gas pressure) was due to the subsequent warming up of the gas. By use as an ionization gauge, the ratio of initial to final equilibrium temperature was computed.

apparatus as an ionization gauge to find the decrease in gas density due to increase in temperature just after the current through the filament was turned on. The positive ion current and electron current were measured at twenty second intervals for at least five minutes, beginning about one minute after the filament current had been turned on, and then at less frequent intervals until stable conditions were reached. Fig. 3 shows the results of two typical runs in mercury vapor, one with $V_0=160$ volts and the other with $V_0=320$ volts. The ordinates are numbers of positive ions produced per electron in traversing the length of B, per 0.001 mm pressure of the vapor.[9] The values of this number at time 0, i.e., at room temperature, are obtained by a short extrapolation of the curves back-

[9] The difference in the shape of these curves is due, for the most part, to the differences in initial pressures and in changes of pressure during the runs. That is the reason for giving the pressures in the figure.

ward. Thus with $V_s = 160$ volts the final ordinate is 91.9 percent of the initial one, and corresponds to a temperature rise of 26° above the room temperature of 25°; and with $V_s = 320$ volts the final ordinate is 90.7 percent of the initial one and corresponds to a temperature rise of 30° above the room temperature of 23°. From the consideration of nine such runs, it was decided that 51°C best represents the temperature of the gas in chamber B throughout the various observations. The possible variations from this temperature would not introduce any appreciable error.

Methods of handling the gases. The hydrogen was prepared by electrolysis of dilute sulfuric acid and was purified by passing over phosphorous pentoxide and through charcoal immersed in liquid air. It was admitted to the experimental tube through a trap immersed in liquid air, and there was also a liquid air trap between the experimental tube and the McLeod gauge and diffusion pump connections. Owing to the very rapid "clean up" of the hydrogen, a reservoir of about 5 liters capacity was attached to the tube to reduce the rate of change of pressure. The pressure was measured at about ten minute intervals during the runs, and the time of each current reading was noted, so that the proper pressure could be used for each individual calculation of the ionization per electron per unit pressure.

The argon was purified by prolonged arcing between calcium electrodes and was admitted to the experimental tube through a liquid air trap. To insure the purity of the neon and the helium in the tube, a charcoal trap, a tube containing copper and copper oxide, and a high pressure diffusion pump were added to the system in such a way that the gas could be circulated by the pump through the glowing copper and copper oxide and the charcoal, which was immersed in liquid air. This circulation was not continued while observations were being made, since the action of the circulating pump caused somewhat erratic variations in the gas pressure within the experimental tube. The helium and neon were each spectroscopically free from each other before being admitted to the system.

The nitrogen first used was generated by the reaction of sodium nitrite and ammonium chloride, stored in contact with phosphorous pentoxide and admitted through a tube immersed in liquid air. After finding that some ionization set in at about 10 volts (see Fig. 5) it was thought that possibly there might be some nitrogen oxides present, so that other runs were made using nitrogen generated by the action of bromine on ammonia and stored over phosphorous pentoxide—a method which is supposed to yield very pure nitrogen.[10] However, the experimental results with the gas prepared by the two methods were almost identical.

[10] Waran, Phil. Mag. 42, 246 (1921).

While making the observations on mercury vapor, the liquid air was removed and the pressure varied for different runs by varying the room temperature. The slight temperature changes during a run were taken account of by noting at ten minute intervals the temperature of a thermometer placed in the vicinity of the system, and the time of each current measurement was noted, as in the case of hydrogen.

For the observations on hydrogen chloride, the gas was generated by the action of sulfuric acid on hydrochloric acid, passed through a sulfuric acid wash bottle, over phosphorous pentoxide and solidified in a tube immersed in liquid air. Then any uncondensed gas was pumped off, and the condensed material was allowed to evaporate into the 5 liter reservoir, after which it was recondensed and the residue again pumped off. This process was repeated until no uncondensable gas remained. The gas pressure in the 5 liter reservoir was then adjusted so that the rate of flow into the experimental system through a fine capillary leak would give a suitable pressure in the experimental tube when the diffusion pump was running. In this way there was no opportunity for the accumulation of products of slow reaction of the HCl vapor on the metallic electrodes. Due care was taken in the arrangement of the McLeod gauge and pump connections so that the gauge would give the true pressure in the experimental tube. Since liquid air temperature is too low to give a suitable vapor pressure of hydrogen chloride, a temperature between 10° and 25° higher than liquid air temperature was maintained in the traps for keeping out mercury vapor, by surrounding the traps with cylinders of brass closed at the bottom, these in turn being surrounded by large glass test tubes immersed in liquid air. By allowing about an inch of the brass cylinder to extend above the top of the liquid air flask, the pressure of the hydrogen chloride could be made as high as about 0.015 mm. Since there was usually a slight pressure change during a run, the same method of obtaining the correct pressure for each observation was used as in the cases of hydrogen and mercury vapor.

Potential at the center of chamber B. In order to prevent any appreciable number of electrons from striking the positive ion collector, V_r had to be made slightly larger than V_a. Thus the space through which the electrons passed within the chamber B was not field free, but had a potential distribution, probably such as shown in the central part of Fig. 1. The potential with respect to the filament would be a minimum at the center of B. Thus an electron, entering B with the speed corresponding to V_a, would be retarded until it reached the center, and then would be accelerated so that it would pass out of B with the same speed as that with which it entered, provided it suffered no inelastic collision on the way. Two

methods were used in determining the potential at the center of B. The first consisted in measuring the total electron current I_- while V_s was kept constant and V_r varied, for a series of values of V_s both in a vacuum and in hydrogen. When I_- was plotted against V_r, a marked change in slope was found in every curve at a value of V_r about 2.5 times that of V_s. This critical value of V_r was interpreted as being the one above which electrons were turned back before reaching the center of B, some striking the tube T or the under side of the shield containing it. Therefore V_m, the potential at the center of B, may be taken as $V_s - 0.4|V_r|$, where $|V_r|$ represents the numerical value of the retarding potential applied between B and C.

The second method of determining V_m was to place a sensitive galvanometer in series with the 22.5 volt battery B (Fig. 2), connecting the two sets of vanes of the ion trap, and noting at what value of V_s, for a given V_r, electrons began getting through B into the ion trap. It was found that they began to get through when V_s was from 0.40 to 0.45 times $|V_r|$, thus confirming the conclusion that $V_m = V_s - 0.4|V_r|$, to a close approximation.

Methods of measurement and calculation. Series of measurements were made on all the gases investigated by noting G_- and G_+ as V_s was varied from below the minimum ionizing potential to about 320 volts (410 volts in the case of neon to make sure that the voltage for maximum I_+ had been passed) with $|V_r|$ always about 1.5 volts greater than V_s. Readings were taken at intervals of one volt to above twice the ionizing potential; then of two volts to about 100 volts; of five volts to about 180, and then of ten volts over the rest of the range. Preliminary tests showed that the ratio I_+/I_- was independent of the filament temperature, i.e., of I_-, over a wide range. For convenience, about the same filament current was used all through the investigation and the galvanometers were calibrated at the beginning and end of each individual run. Several runs were made at somewhat different pressures with each gas. The only limitations in the pressures and currents which could be used were (1) that these must be large enough to give sufficient ionization for accurate measurement, and (2) that they must not be so large as to allow appreciable ionization by cumulative action or by more than one impact by an electron.

From the readings of G_- and G_+, the galvanometer and electrometer calibrations and the gas pressures, the ratio $I_+/(I_- p)$, where p is the pressure of the gas in mm of mercury, was calculated. Then from the results of three or more such runs which agreed within 2 percent with one another over most of the range for each gas, the mean values of this ratio were found for each voltage V_s. When these mean values were plotted

against the values of V_a they gave such curves as curve *a* in Figs. 4 and 5. The ordinates of this curve should give the average number of ionizing collisions made per electron while moving a distance equal to the length of B (2.8 cm) through the gas at 1 mm pressure with velocity corresponding to V_a, if it were not for the fact that the space within B is not field free and consequently the electrons do not all have the velocity V_a when they strike the gas molecules. Two methods were used to take into account this uncertainty, (1) by calculation based on the distribution of potential within B, and (2) a direct method whereby the desired quantity can be set by experiment between narrow limits.

First method. Of several assumptions made regarding the variation of potential along the path of the electrons in B, the one which gave the most reasonable results was the assumption that the potential varies at a uniform rate from the end to the center. Then the value of the potential V (with respect to the filament) at any point x in B is given by

$$V = V_a - \int_x^l E dx = V_a - E(l-x) ,$$

where l is the distance from the center to the end of B, x is the distance of the point x from the center of B and E is the electric intensity (supposed constant). At the center, $x=0$, hence

$$V_m = V_a - El = V_a - 0.4(V_a - V_c)$$

where $V_c = V_a - |V_r|$ is the potential of the collecting electrode. Thus $E = 0.4\ (V_a - V_c)/l$. Substituting this above, and remembering that V_c in our experiments was only 1.5 volts, we have approximately

$$V = V_a(0.6 + 0.4x/l) . \qquad (1)$$

Let $M = I_+/(I_- p)$ stand for the observed ionization per electron per unit pressure in the chamber B. Let $f(V)$ be the average number of ionizing collisions made by an electron if it passed through B with uniform velocity of V volts, at unit pressure. Then we should have

$$M = \int_{V_m}^{V_a} f(V) d(x/l) .$$

Since $V_m = 0.6 V_a$, and differentiation of Eq. (1) gives $d(x/l) = (2.5/V_a)dV$, we have

$$M = (2.5/V_a) \int_{0.6V_a}^{V_a} f(V) dV .$$

By differentiation,

$$0.4\, d(MV_a)/dV_a = f(V_a) - f(0.6\, V_a) . \qquad (2)$$

In applying this equation to determine $f(V_s)$ from the experimental values of V_s and M, we have two cases to consider:

If $V_s < 1.67$ times the minimum ionizing potential V_i, then $f(0.6\,V_s)=0$, and we have

$$f(V_s)=0.4\,d(MV_s)/dV_s. \qquad (3)$$

If $V_s > 1.67\,V_i$, then

$$f(V_s)=0.4\,d(MV_s)/dV_s+f(0.6\,V_s) \qquad (4)$$

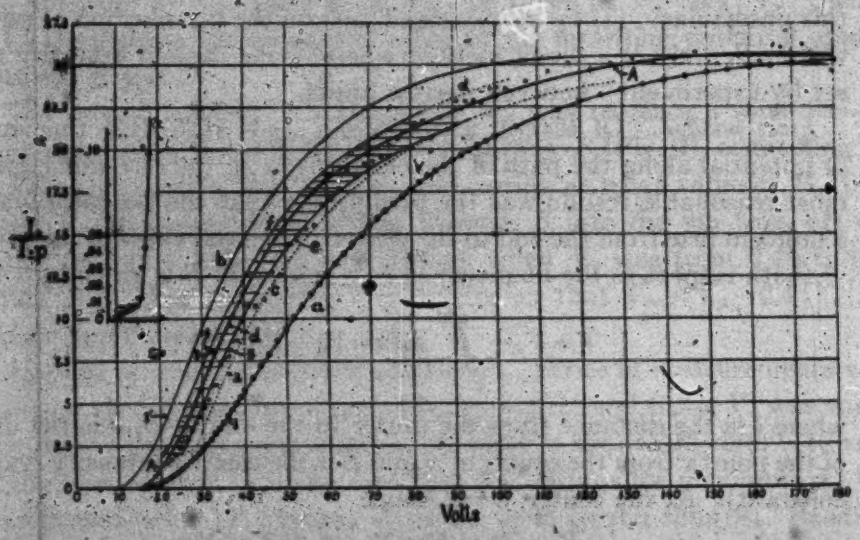


Fig. 4. Curves for nitrogen; positive ions formed per electron per mm pressure per 2.8 cm path as a function of energy of electrons, in volts. Curve *a* gives experimental results when $V_r = V_s + 1.5$ volts, thus with primary electrons prevented from reaching *C*. Curve *b* gives the same values plotted against the minimum energy V_m instead of the maximum energy V_s. The true curve lies between these. Curve *c* gives experimental values when V_r was adjusted for maximum ionization, and curve *d* gives the same for minimum voltage V_m. Curves *e* and *f* were obtained by correcting *c* and *d* for stray electron current. The true curve lies between *e* and *f* and is taken as curve *A*. Crosses are points which were computed from curve *a* by method (1).

The values of $f(V_s)$ were calculated for the different voltages used, by means of Eq. (3) and (4) and plotted at the mid-points $V_s - \frac{1}{2}\,dV_s$, giving results such as are shown by the crosses in Figs. 4 and 5. A rather marked change in slope was noted in all of the M curves at a value of V_s approximately twice the ionizing potential, and this break was still more pronounced in the $f(V_s)$ curves. It was at first suspected that these breaks might be due to ionization of highly excited molecules, or by the double ionization which might occur if a molecule, excited by an energy at least twice the minimum ionizing energy, should make a collision of the second kind with a neutral molecule. Such effects should, however, tend

to disappear at very low gas pressures, whereas we found that the curves, including this break, were identical down to extremely low pressures. In the second method, described below, it was found that this break shifted according to the value of V_r, so that we are inclined to attribute it to a peculiarity of the field within B, due to lack of radial symmetry of the collecting electrode system. It probably indicates a second order error in the values of M and $f(V_a)$ in the lower voltage ranges.

The second method for finding the number of ionizing collisions which would be made by an electron moving with a uniform speed V_a through B in gas at unit pressure, can be best explained by referring to Fig. 4. Consider, for instance, the experimental reading marked 1. Here the electrons entered the chamber B with velocity of 36 volts and reached the center of B with velocity of 0.6 of 36, or 24 volts. The ordinate at 1 must therefore be the value of $f(V_a)$ corresponding to some value of V_a between 36 and 24 volts. In other words, the corresponding point on the $f(V_a)$ curve must be somewhere between 1 and 1'. Similarly for every point on curve a there is a corresponding point on curve b which is shifted to the left by an amount 0.4 of V_a. The true curve for $f(V_a)$ must lie between the curves a and b.

Now, by decreasing the field V_r to a value considerably less than V_a, keeping V_a constant at 36 volts, it was found that the current I_+ increased to a maximum value when V_r was 11 volts, and then decreased with further decrease in V_r. The reason for this is that decrease in V_r produced two opposing effects: (1) It diminished the retardation of the electrons, thus causing them to traverse B with speeds more nearly equal to V_a, and thus increased the ionization produced by them; (2) it permitted some electrons to reach the collecting electrode, and thus diminished the apparent amount of ionization. The observed value of I_+ corresponds to point 2 in Fig. 4. Owing to the electrons which reached the collecting electrode, the true ionization must have been somewhat greater than this. The amount by which it was greater was determined by making a similar measurement with the gas removed from the tube, so that the stray electron current only was measured, and this was checked by similar measurements in the gas at values of V_a less than V_i. Adding this to the current corresponding to point 2 gives the current which would have been observed with V_r equal to 11 volts, had there been no reverse current due to electrons. This ordinate at point 3 corresponds to electrons which entered B with velocity 36 volts, and whose velocity fell by 0.4 of 11 volts, or by 4.4 volts within B. Thus the ordinate is the value of $f(V_a)$ for some value of V_a between 36 and 31.6 volts. Thus the limits within which the value of $f(V_a)$ must lie have been much narrowed down; it must lie be-

tween points 3 and 4. A consideration of all the factors involved led to the choice of point 5 as the most probable point, and it is certain that this value of V_e and $f(V_e)$ cannot be in error by more than a few percent. In this way, the values of $f(V_e)$ were found and plotted as curve A, which lies between the experimentally fixed limits shown by curves e and f.

Of the two methods, the second is the more reliable in that it does not depend on any assumption regarding the distribution of potential within B. The agreement between the two methods is indicated by the way in which the crosses are distributed with respect to the experimental limits

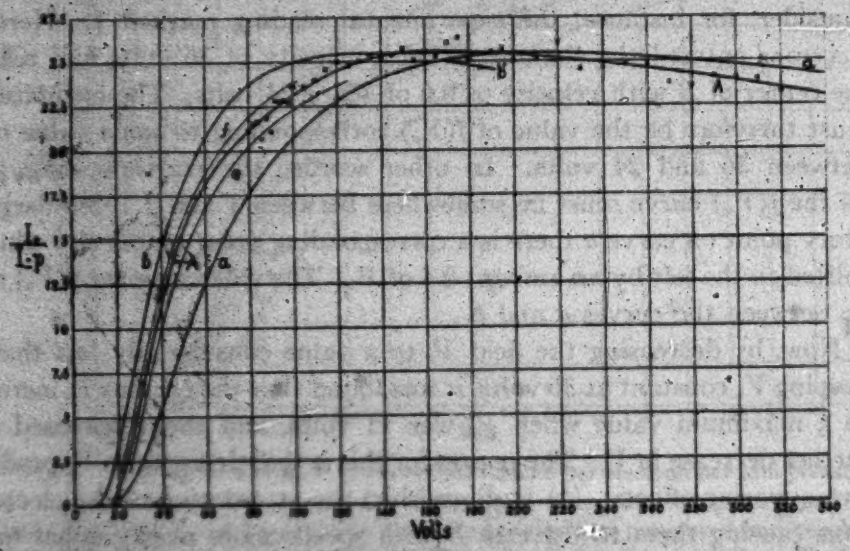


Fig. 5. Extension of Fig. 4 to 340 volts.

shown by the shaded region between curves e and f. The agreement is best at the higher voltages, where the variation of $f(V_e)$ with V_e is less rapid. Curve A has been drawn with reference to the second method at the lower voltages, and with reference to the first method at the higher voltages, where the two methods converge to give the same results. Curve A gives, for nitrogen, the average number of ionizing collisions which would be made by an electron moving with constant speed V_e through chamber B containing the gas at 1 mm pressure. Fig. 5 shows the same results, continued to the higher voltage ranges.

Discussion of Results

If the values of the ordinates of curve A are divided by the length of the chamber B, they give the average number N of ionizing collisions per electron per cm path per mm gas pressure as a function of the velocity. The assembled results of our experiments are shown in Fig. 6, where N

stands for the quantity defined just above. It is of interest to note that the value of N continues to decrease with still greater electron speeds. For air, according to Kossel[8] N decreases from about 10 at 200 volts to 3.3 at 1000 volts, 0.4 at 30,000 volts and 0.18 for β-rays.

The probability P of ionization at an impact may be found by dividing these values of N by the number of collisions per cm path made by an

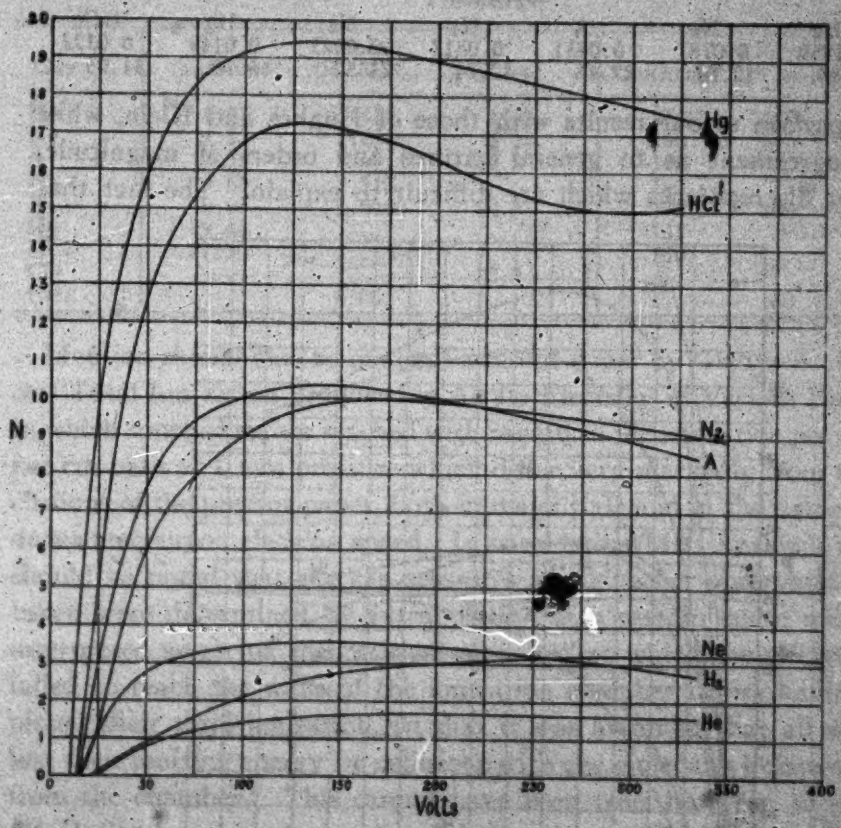


Fig. 6. Number of positive ions formed per electron per cm path through gas at 1 mm pressure, as a function of the electron energy in volts.

electron moving through the gas at 1 mm pressure. Although there is some uncertainty regarding the true values of this number, the experiments of Ramsauer[11] and Mayer[12] indicate that the ordinary kinetic theory value of electronic mean free path is at least approximately correct at speeds as large as those in which we are interested, except for argon at the lower speeds. We shall, therefore, assume that the electronic mean free path equals $4\sqrt{2}$ times that of the gas molecules. The values are given

[11] Ramsauer, Ann. der Phys. 64, 513 (1921); 66, 546 (1921).
[12] Mayer, Ann. der Phys. 64, 451 (1921).

in Table I. They are calculated from values given in "High Vacua," by Dushman, except in two cases for which the data were not available there and were obtained from Kaye and Laby's Tables. All are calculated for a temperature of 25°C. The values of the probability P are shown in Fig. 7.

TABLE I

Gas:	He	Ne	A	H_2	N_2	Hg	HCl
l :	0.1259	0.0787	0.0451	0.0817	0.0425	0.0149	0.0322
$1/l$:	7.95	12.80	22.18	12.24	23.52	66.70	31.05

A comparison of our results with those of Hughes and Klein, while showing agreement as to general features and orders of magnitude, brings out discrepancies which are difficult to explain. The fact that

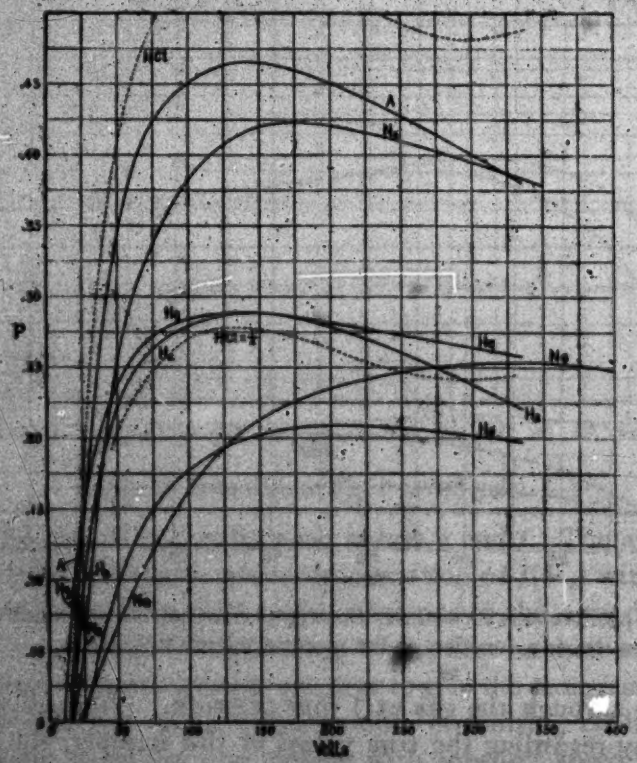


Fig. 7. Probability of ionization at an impact as a function of the electron energy in volts, assuming kinetic theory values of electronic mean free paths.

their values are consistently smaller than ours may be due to the fact that they appear not to have taken account of the heating of the gas in the apparatus by the filament. We feel that their results are definitely too low, since they fall below the lower limit set by curves, such as curve s of Figs. 4 and 5, which are the direct result of measurement and depend on no calculations or assumptions, but only on the calibration of the gal-

vanometers and the McLeod gauge. Some aspects of this comparison are shown in Table II. This table also contains values from a recent paper by Jesse.[13] Although he does not claim much accuracy for his absolute values of N, his results agree more closely with ours than do those of Hughes and Klein.

TABLE II

Gas	N (max) (authors)	N (max) (H. & K.)	N (max) (Jesse)	V_0 (max) (authors)	V_0 (max) (H. & K.)	V_0 (max) (Jesse)
He	1.65	0.881	1.61	210	150	140
Ne	3.22	1.828	3.16	340	160	220
A	10.33	7.65	14.5	140	80	100
H_2	3.55	2.518	.....	145	73.5	...
N_2	9.96	7.640	10.3	175	100	100
Hg	19.44	.....	.....	135	.....	...
HCl	17.30	.....	.....	130	.....	...
CO	.....	.....	12.8	...	.....	120
CH_4	.....	8.06	.....	...	80	...

Mention should also be made of a recent paper by Gladys A. Anslow[14] on "Total Ionization Produced in Air by Electrons of Various Energies," in which conclusions are reached with regard to the ionization per electron per cm path at 1 mm pressure which differ very markedly from the conclusions of the present paper, both in magnitude and in the nature of the dependence upon electron speed. In considering Miss Anslow's work, it should be noted that the gas pressures at which her observations were taken were determined by extrapolation of a certain curve which was interpreted as giving the "critical pressure" at which the electrons just failed to reach the walls of the ionization chamber before having completed their total ionization, so that it was assumed that all electrons lost their ionizing energy by collisions with gas molecules before escaping from the chamber. This cannot have been true, however, as a simple calculation based on electron mean free paths shows. For all of her voltages below 1000 volts, an appreciable number of electrons would have traversed the ionization chamber without having collided at all; below 300 volts the majority would have thus escaped collision, while at the maximum of her curve, Fig. 6, not more than one percent of the electrons would have collided. Thus the interpretation of the results at the lower voltages is incorrect and these results cannot be taken as inconsistent with the results of the present paper. Incidentally, we believe that the maximum in Miss Anslow's Fig. 6 is due to the combination of the variation in the number of electrons which collide and the variation of the probabilities of ionization at the different pressures and voltages used.

[13] W. P. Jesse, Phys. Rev. 26, 208 (August, 1925).
[14] Gladys A. Anslow, Phys. Rev. 25, 484 (1925).

On the basis of measurements with the ionization gauge, Dushman[15] suggested that the ionization in different gases is proportional to the total number of electrons in the molecules of the gases. The present results do not support this suggestion as a quantitative relation. It may be, however, that the proposed relation is more accurate at higher voltages than those at which we worked—as might be expected on theoretical grounds and as is indicated by the early work of Kossel,[16] who made the same suggestion on the basis of measurements at 1000 volts.

Finally, the apparent ionization of nitrogen at about 10 volts (see Fig. 4) raises an interesting question of interpretation. As shown in the insert, this is extremely weak as compared with the ionization setting in at the ordinary ionizing potential. Three possibilities present themselves: (1) It may represent a weak and hitherto undiscovered type of ionization of nitrogen; (2) it may be due to photo-electric effect on the collecting electrode C by radiation excited in the gas; (3) it may be due to electron emission from the collecting electrode C produced by contact with "excited" or "active" molecules of nitrogen. In opposition to the second suggestion is the fact that in no other gas was there any detectable current which could be ascribed to photo-electric effect; the scheme for eliminating complications from this cause seemed to be quite successful. In favor of the third suggestion is the fact that this observed critical potential agrees well with the internal energy of at least one type of active nitrogen, which has been placed at 9.52 volts by Saha and Sur,[18] as revised by Foote, Ruark, and Chenault.[17] If this is the correct interpretation, the detection of the active nitrogen by an apparatus relatively insensitive to the photo-electric effects would be due to the greater probability of electron emission at a collision of the second kind between an excited molecule and the metal than by photo-electric action of radiation. If this be true, it must still be remarked that the efficiency of these low voltage impacts in producing active nitrogen must be quite small, else Duffendack would have detected it in his low-voltage arcs.[18] We hope later to be able to give a definite answer to this question.

Note added with proof. Further consideration of the work by Hughes and Klein[8] and by Jesse[13] indicates that in both cases the assumed values of primary electron current must be in error. The former are too large, owing to an incorrectly assumed linear relation between current and field on one side of the grid. The latter are too small on account of neglect of

[15] Dushman, "High Vacua"; Dushman and Found, Phys. Rev. 23, 734 (1924).
[16] Saha and Sur, Phil. Mag. 48, 421 (1924).
[17] Foote, Ruark, and Chenault, Phys. Rev. 25, 241 (1925).
[18] Duffendack, Phys. Rev. 20, 665 (1922).

secondary electrons which subtract from the primary electron current. Experiments are being undertaken to see whether these corrections are adequate to account for the discrepancies in the three experiments on this subject. It may be noted that in the present work both the ionization and the primary electron currents were measured directly, and that secondary electrons were avoided by use of the electron trap.

PALMER PHYSICAL LABORATORY,
PRINCETON, NEW JERSEY,

PLAINTIFF'S EXHIBIT No. 195.

COPY

40380 - 4

Statement of Arnold
Filed Sept. 2, 1916
Examined " 8, 19 "
Approved 19 W.

UNITED STATES PATENT OFFICE

ARNOLD
v.
LANGMUIR

Interference No. 40,380

Subject: Thermionic Devices and Method of Constructing and Operating the same.

PRELIMINARY STATEMENT OF HAROLD DeF. ARNOLD

State of New York
County of New York
ss.

ARNOLD

HAROLD DeFOREST ARNOLD, in the County of New York, State of New York, being duly sworn, deposes and says:

I am one of the parties to the interference declared by the Commissioner of Patents on August 8, 1916, between my application for Letters Patent for Thermionic Devices and Method of Constructing and Operating the Same, filed November 2, 1915, and an application of Irving Langmuir.

I conceived the invention set forth in the declaration of interference and disclosed the same to others in the latter part of 1912.

The first written records evidencing invention were made on various dates in the latter part of 1912 and at frequent intervals thereafter, and the first drawing illustrating the invention was made on March 24, 1913.

The invention was reduced to practice on December 26, 1912 and again on March 24th, and April 25th of 1913.

Since the date of reduction to practice, the invention has been used in wire and wireless telephonic communications carried on by the American Telephone and Telegraph Company and the Western Electric Company, Incorporated, both in experimental and commercial work.

(signed) HAROLD DeFOREST ARNOLD.

Sworn to and subscribed before me this 1st day of September, 1916.

(signed) Robert E. Williams,

Notary Public.
New York County No. 297,
New York Register No. 7245.

PIW-DC
PIW

PLAINTIFF'S EXHIBIT No. 196.

COPY

Room No. 261. Paper No. 6.
Address Only
"The Commissioner of Patents,
Washington, D. C."
And not any official by name.

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE
Washington, D. C.

IAW September 8, 1916.
In Re Interference No. 40380.

ARNOLD
v.
LANGMUIR
} Before the Examiner of Interferences.

U. S. PATENT OFFICE
Interference Division
SEP. 8 1916
MAILED

H. D. Arnold, c/o John G. Roberts, New York, N. Y.

Please find below a communication from the Examiner in charge of Interferences in regard to the above-cited case.

Very respectfully,
(signed) THOMAS EWING,
Commissioner of Patents.

In the preliminary statement of Arnold the allegations with respect to conception, disclosure and written description are too indefinite. The exact day and month in 1912 when these acts took place should be set forth.

Arnold is given until September 18, 1916, within which to file an amended statement overcoming these objections. For failure to so amend he will be restricted to December 31, 1912, for conception, disclosure, and first written description.

(signed) LOUIS E. GILES
Acting Ex'r of Intfs.

PLAINTIFF'S EXHIBIT No. 197.

COPY

Room No. 261. Paper No. 9.
Address only
"The Commissioner of Patents,
Washington, D. C."
and not any official by name.

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE
Washington, D. C.

IAW September 18, 1916.

IN RE Interference No. 40380.

ARNOLD
v.
LANGMUIR } Before the Examiner of Interferences

U. S. PATENT OFFICE
Interference Division
SEP 16 1916
MAILED

Please find below a communication from the Examiner in charge of Interferences in regard to the above-cited case.

Very respectfully,
(signed) THOMAS EWING
Commissioner of Patents.

The telegraphic request filed on behalf of Langmuir is approved and in accordance therewith the time for filing preliminary statements is hereby extended to and including September 25, 1916.

Any further extension should be sought by stipulation or motion.

(signed) H. E. STAUFFER,
Examiner of Interferences.

PLAINTIFF'S EXHIBIT No. 193.

COPY

40380 – 4 & 10

Statement of Arnold
Filed Sept. 18, 1916
Approved " 29, 1916 W.

UNITED STATES PATENT OFFICE

ARNOLD
v.
LANGMUIR

Interference No. 40,380

Subject: Thermionic Devices and Method of Constructing and Operating the Same.

PRELIMINARY STATEMENT OF HAROLD DeF. ARNOLD.

State of New York
County of New York } ss.

HAROLD DeFOREST ARNOLD, in the County of New York, State of New York, being duly sworn, deposes and says:

I am one of the parties to the interference declared by the Commissioner of Patents on August 8, 1916, between my application for Letters Patent for Thermionic Devices and Method of Constructing and Operating the Same, filed November 2, 1915, and an application of Irving Langmuir.

I conceived the invention set forth in the declaration of interference and disclosed the same to others on or about November 1, 1912.

The first written records evidencing invention were made on November 16, November 19, November 29 and December 27, all of 1912, and at frequent times thereafter. The first drawings illustrating the invention were made on November 16, November 19, November 29, all of 1912, and March 24 of 1913, and at frequent times thereafter. The invention was reduced to practice on November 29 of 1912, March 24, April 25 and May 12 of 1913.

Since the date of reduction to practice, the invention has been used in wire and wireless telephonic communications carried on by the American Telephone and Telegraph Company and the Western Electric Company, Incorporated, both in experimental and commercial work.

(signed) HAROLD DeFOREST ARNOLD

Sworn to and subscribed before me this 15th day of September, 1916.

(signed) Ella Edler
Notary Public No. 23,
New York County
Commission Expires
March 30, 1917.

PIW–AA

PLAINTIFF'S EXHIBIT No. 199.

COPY 32.

MAIL ROOM
Jan. 15
1917
U. S. PATENT OFFICE

UNITED STATES PATENT OFFICE

ARNOLD
vs. Interference No. 40,380
LANGMUIR

COMMISSIONER OF PATENTS,
Washington, D. C.

Sir:

Referring to the order of the First Assistant Commissioner, January 11, 1917, the following additional particulars are now given in regard to the citation of articles appearing on page 6 of Arnold's Supplementary Motion to Dissolve:—

The article in Annalen der Physik, Vol. 28, pages 537-552 (1909), comprising sixteen (16) pages, is considered to be of importance and will be relied upon.

The entire articles of Majorani published in Atti Della Reale Accademia dei Lincei, Vol. 21, pages 235-239 inclusive, and in the same publication, pages 274-277 inclusive, are considered to be of importance and will be relied upon. These articles comprise respectively five pages and four pages.

The article by Fleming in the Proceedings of the Royal Society, January 1905, pages 476-487 inclusive comprises twelve (12) pages, three pages of which are given up to tables, and all of this article is considered to be of importance.

The article by McClelland in Proceedings of Cambridge Philosophical Society, Vol. 10, (1900), page 241, is hereby withdrawn from consideration.

The address by Dewar before the Royal Institution of Great Britain, June 7, 1907, published in Engineering, Vol. 83, page 781, June 14, 1907, is all comprised on one page.

The article in the Sitzungsberichte der Physicalisch Medischen Gesellschaft, Vol. 37, pages 312-315 (1905), comprises only four pages, all of which are pertinent and should be considered.

Respectfully,
(signed) D. C. TANNER,
Attorney for Arnold.

468 West Street,
New York, January 13, 1917.

DCT-DG

PLAINTIFF'S EXHIBIT No. 200.

DEPARTMENT OF COMMERCE

UNITED STATES PATENT OFFICE

To all persons to whom these presents shall come, Greeting:

THIS IS TO CERTIFY that the annexed is a true copy from the records of this office of Letter to Office, filed February 8, 1918, in the matter of

Interference Number 40, 880,

ARNOLD VS. LANGMUIR,

Subject Matter:—

Electric Discharge Apparatus and the Process of Preparing the Same.

IN TESTIMONY WHEREOF I have hereunto set my hand and caused the seal of the Patent Office to be affixed, at the City of Washington, this fourteenth day of September in the year of our Lord, one thousand nine hundred and twenty-six and of the Independence of the United States of America the one hundred and fifty-first.

[SEAL]

THOMAS E. ROBERTSON,
Commissioner of Patents.

ATTEST:
D. E. WILSON,
Chief of Division

IN REPLY ADDRESS
THE SECRETARY OF THE NAVY
AND REFER TO NO. 40380—85

NAVY DEPARTMENT
WASHINGTON

VR/WSS/26840

February 7, 1918.

From: Secretary of the Navy
To: Commissioner of Patents, Washington, D. C.

SUBJECT: Case of Arnold v. Langmuir, No. 40,380.

1. Both Dr. Arnold and Dr. Langmuir are engaged in important work for the Navy Department.

2. The case of Arnold v. Langmuir was postponed for a period of six months because of this fact. Both of these gentlemen are still actively engaged practically for a great majority of their time and, if it can be consistently done, it is requested that a further extension of six months in the taking of testimony be granted.

3. It is understood that both of these gentlemen and their counsels will be glad to agree to this extension if you can see fit to grant it.

F. W. ROOSEVELT,
Acting

PLAINTIFF'S EXHIBIT No. 201.

Exhibit.

OPTION.

AGREEMENT made this Sixteenth day of December, 1912, between PETER COOPER HEWITT, of New York City, and the AMERICAN TELEPHONE AND TELEGRAPH COMPANY, a New York corporation, hereinafter called the Telephone Company.

In consideration of the sum of Thirty Thousand Dollars ($30,000.), paid by the Telephone Company to the said Hewitt, the receipt of which is hereby acknowledged, the said Hewitt agrees for himself, his legal representatives and assigns, as follows:

1. If, within one year from the date hereof, the Telephone Company pays to Hewitt One Hundred and Ten Thousand Dollars ($110,000) in addition to the amount mentioned above, and executes and delivers to Hewitt agreements in the forms A and B hereto attached (excluding some of the patents therein mentioned or referred to, if the Telephone Company so elects), Hewitt will thereupon execute (and cause the Cooper Hewitt Electric Company to execute) both of said agreements, (and the Westinghouse Cooper Hewitt Company, Limited, to execute Agreement B,) in the form delivered by the Telephone Company, and also duplicate originals thereof, and will deliver to the Telephone Company such executed duplicate originals.

2. Hewitt will not object to the Telephone Company making and using, for purposes of experiment, test and demonstration, C. H. T. devices, as defined in attached agreements, embodying or containing or operating in accordance with the inventions referred to in the attached form of license up to the date of exercise of said option by the Telephone Company, but not beyond a period of one year from the date hereof, if said option is

not exercised within said period; and Hewitt will make no claim against the Telephone Company, or those operating under its authority, because of such making and using.

If the said option is exercised, the Telephone Company, its successors and assigns, may continue to use and may sell or lease to others for use and sale, or rental, the apparatus made during the option period, upon paying $30 per installation, as provided in the attached form of license.

3. Hewitt warrants that he has full power and authority to grant this option and to enter into the license agreement hereto attached, and that he has not made and will not make any agreement in conflict herewith or with his ability to execute and carry out the provisions of the attached license agreement.

IN WITNESS WHEREOF, the said Hewitt has executed this instrument the day and year first above written.

(Signed) Peter Cooper Hewitt.

The Cooper Hewitt Electric Company, holding the legal title to some of the patents referred to in the foregoing option and attached form of licenses hereby, upon behalf of itself and on behalf of the Westinghouse Cooper Hewitt Company, Limited, which also holds the legal title to some of the said patents, all of the capital stock of which Company, is held and owned by the Cooper Hewitt Electric Company, acknowledges to and agrees with the American Telephone and Telegraph Company that so far as concerns the Cooper Hewitt Electric Company and the Westinghouse Cooper Hewitt Company, Limited, or others claiming under it or them, the above mentioned Peter Cooper Hewitt has full right and power to grant the foregoing option and to enter into the attached license agreements A and B, and the Cooper Hewitt Electric Company to the same extent hereby ratifies and confirms the foregoing option and the attached license

agreements upon its own behalf and on behalf of the Westinghouse Cooper Hewitt Company, Limited, and it agrees that it and said last mentioned Company will execute said agreements when requested so to do by the said Peter Cooper Hewitt.

COOPER HEWITT ELECTRIC COMPANY,
By
(Signed) Charles B. Hill,
Vice President.

Attest:

(Signed) Charles A. Terry,
Secretary.

COOPER HEWITT ELECTRIC Co.
By
(Signed) Charles B. Hill.

Attest:
(Signed) Charles A. Terry,
Secretary.

State of New York,
County of New York. } ss.:

On this Sixteenth day of December, 1912, before me personally came PETER COOPER HEWITT, to me known and known to me to be the individual described in and who executed the foregoing instrument, and he acknowledged to me that he executed the same.

(Signed) ROBERT FOSTER JAMES,
Notary Public,
N. Y. Co. No. 13 etc.

State of New York,
County of New York. } ss.:

On this Sixteenth day of December, 1912, before me personally came CHARLES B. HILL and CHARLES A. TERRY, to me known, who being by me severally duly sworn did depose and say; the said Charles B. Hill that he resides in Montgomery, New York; that he is Vice President of the Cooper Hewitt Electric Company, the corporation described in and which executed the above instrument; the said Charles A. Terry that he resides in New York City; that he is the Secretary of the said corporation; that they know the seal of said corporation; that the seal affixed to said instrument are such corporate seal; that they were so affixed by order of the Board of Directors of said corporations, and that they signed their names thereto by like order.

(Signed) ROBERT FOSTER JAMES,
Notary Public, etc.

PLAINTIFF'S EXHIBIT No. 201-A.

Agreement A.

UNITED STATES LICENSE.

AGREEMENT made this day of 191 , between PETER COOPER HEWITT of New York City and the AMERICAN TELEPHONE and TELEGRAPH COMPANY, a New York Corporation, herein called the Telephone Company.

WHEREAS, the said Hewitt has made many inventions, among which are those set forth in the following patents of the United States:

No. 749,791, dated January 19, 1904,
No. 749,792, dated January 19, 1904,
No. 749,793, dated January 19, 1904,
No. 758,650, dated May 3, 1904,
No. 781,001, dated January 31, 1905,
No. 781,002, dated January 31, 1905,
No. 954,434, dated April 12, 1910,
No. 991,304, dated May 2, 1911,

and

WHEREAS, said enumerated patents and other patents for the inventions of said Hewitt were assigned to the Cooper Hewitt Electric Company, a New York corporation, under certain agreements dated March 7, 1900 and November 7, 1902, between the said Hewitt and George Westinghouse, but the said Hewitt retained under said agreements and now owns, for himself and his assigns, the exclusive rights under all of said patents

for certain uses, among which is their use for C. H. T. devices as hereinafter defined; and

WHEREAS, the Telephone Company desires a license to utilize said inventions in such apparatus as hereinafter set forth;

Now, in consideration of the mutual agreements herein contained, it is agreed as follows:

1. Hewitt hereby grants to the Telephone Company the right and license to make or cause to be made for it and to use gas or vapor electric apparatus for creating, transmitting or receiving or relaying or repeating or amplifying or boosting telephonic or telegraphic electric currents, waves or impulses in telephone or telegraph systems employing wires or metallic conductors connecting stations (all of which devices are, for convenience, herein called C. H. T. devices), embodying or made or operating in accordance with any and all inventions which he has heretofore made, and to sell or lease such C. H. T. devices to others and to license them to sell, use or lease the same, which license shall continue to the end of the terms of all patents of the United States which have been or may be obtained on inventions which have been made by Hewitt up to the present date for which applications for United States patents shall have been filed prior to two years from the date hereof.

The foregoing licenses are granted and agreed to be granted for and throughout the United States of America and its territories and dependencies, and shall be exclusive (subject to the provisions hereinafter contained) in the field of telephony and telegraphy using

wires or metallic conductors connecting stations on land lines, including communication over sub-aqueous cables, such as extend through rivers, lakes and seas, and to the immediate outlying land, and shall be non-exclusive for trans-oceanic cable lines; nothing herein shall prevent Hewitt from granting to others rights under his inventions to use C. H. T. devices in trans-oceanic cable lines at intermediate landing points, nor from granting to others the right to make C. H. T. devices for such uses.

2. Hewitt further agrees that as and when, up to January, 1921, he hereafter makes inventions useful in or applicable to C. H. T. devices, he will endeavor to promptly and fully disclose the same to the Telephone Company, and each such invention shall come under this agreement, if the Telephone Company so elects from time to time within one year after the date of each such disclosure. If the Telephone Company does so elect, the Telephone Company shall have, with reference to such inventions, the licenses above expressed to the end of the terms of the United States patents to be granted upon the several inventions so disclosed and brought under his agreement. If Hewitt or the Cooper Hewitt Electric Company does not desire to file and prosecute applications for United States patents upon any such inventions so disclosed to the Telephone Company, Hewitt shall give the Telephone Company an opportunity of filing and prosecuting the same. If the Telephone Company elects to prosecute the same, Hewitt agrees to execute all proper papers in connection therewith and assign to the Telephone Company the invention and United States patents to be issued for the same, the Telephone Company agreeing to grant to Hewitt, free of expense, rights under

said patents for uses in fields other than those of telephony and telegraphy in a broad sense as defined in the last paragraph of this Clause 2.

The Telephone Company agrees that when and if it makes commercial installations of C. H. T. devices embodying any inventions under which this license is granted, it will, up to January 19, 1921, give to Hewitt, but not to his assigns or representatives the opportunity of examining the same and witnessing the operation thereof. Information received by Hewitt from or through the Telephone Company or its interests shall be utilized by Hewitt in his discretion in the interest of the Telephone Company and not to the detriment of that Company.

The Telephone Company further agrees that it will give to Hewitt, but not to his assigns or representatives, an opportunity of acquiring a right to use and of granting to others the right to use any improvements which the Telephone Company may make in C. H. T. devices embodying inventions under which this license is granted, such rights being limited, however, to users for other than telephony or telegraphy in a broad sense, namely, including transmission over conductors on land or transoceanic cables or wireless transmission. Such rights may be acquired by Hewitt on terms to be agreed upon from time to time; it is recognized that no basis for such acquisition can be fixed at present; but the understanding is that Hewitt shall have an opportunity of acquiring such rights or of purchasing such apparatus from the Telephone Company at a fair price, and at a price at least as low as any price acceptable to the Telephone Company, offered by others.

3. The Telephone Company agrees that it will keep books showing the manufacture of said C. H. T. devices by or for it, and the installations of such apparatus made by it or under its authority, which books shall at all reasonable times be open to the inspection of Hewitt or his duly authorized agents.

An "installation" is defined as an apparatus employed to create, transmit, receive, relay, repeat, amplify or boost electric currents, waves or impulses in a circuit or between lines connected or interconnected to form a circuit for transmission of sounds or signals, whether a one-way or two-way working apparatus, and without regard to the number of tubes employed or the particular circuit arrangement of connections, provided, however, that

(a) if the apparatus employed in a given connection or circuit is located at two or more places separated by outside line construction, the apparatus in each such location shall be counted as a separate installation;

(b) If a circuit divides into several branches not reuniting, and independent apparatus is installed in more than one branch of the circuit, then each such apparatus shall count as a separate installation, even although not separated from the others by outside line construction;

(c) if there should be employed apparatus capable of operating simultaneously for several independent circuits, although using one or more parts in common, such apparatus shall be considered as a number of installations equal to the number of independent circuits upon which it is arranged to work simultaneously.

4. The Telephone Company agrees that it will on or before the twentieth day of each January and July, during the term of this agreement, render to Hewitt a statement in writing setting forth the number of installations of C. H. T. devices (embodying or operating in accordance with any of the inventions under which this license is granted, leased, sold or put into use by it or under its authority in the six calendar months immediately preceding that in which each such statement is rendered.)

The Telephone Company further agrees that, subject to the provisions hereinafter contained, it will, at the time of rendering each such statement up to January 19, 1921, the date of expiration of said patents Nos. 749,791 and 749,792, pay to Hewitt an amount in royalties equal to Thirty Dollars ($30) for each such installation so reported. After said date the royalty shall be Ten Dollars ($10) for each additional installation embodying the invention of any unexpired patent or patents in force at the time of each such installation.

Royalties are payable only with reference to installations as above defined and not on tubes or other parts for replacement or renewal, nor upon the same apparatus when transferred to a new location or to other circuits.

5. If the royalties paid under this license with reference to the year 1914 and each year thereafter up to and including 1920 do not amount to at least as much as Ten Thousand Dollars ($10,000) for each year, and the Telephone Company does not, at the time of ren-

dering the statement for the last half of any such year, pay an amount which, added to the royalties then due, brings the total payments for the year up to said sum, Hewitt may, by notice in writing delivered to the Telephone Company on or before March 1 of the year following that for which the payments have been less than said sum, change the exclusive license, herein granted, to a non-exclusive one.

6. If the Telephone Company fails to render statements and pay the royalties due as and when stated above, and fails to repair its default within sixty days after the receipt of written notice thereof from Hewitt, Hewitt may cancel and terminate this agreement by serving on the Telephone Company written notice of his election so to do.

7. In case at any time or times, during the continuance of this license, any of the patents under which this license is granted, are being infringed by the use of apparatus within the field of telegraphy and telephony covered by this license, then the Telephone Company shall have the right to cause a suit or suits for infringement to be brought and prosecuted under such patent at its own cost and expense using the name of Hewitt or the Cooper Hewitt Electric Company, or both, if it so desire. If the attorneys employed by the Telephone Company for prosecuting the suit shall be unsatisfactory to the said Hewitt or to the Cooper Hewitt Electric Company, in case the latter has an interest in such patent, he or it may employ an attorney to take part in the prosecution of the case.

If any patent with reference to which royalty is payable hereunder is held to be invalid by any Court of final jurisdiction or by any inferior Court from whose decree no appeal is taken and prosecuted within the time prescribed by law, the Telephone Company shall thereafter be under no obligation to pay royalties with reference to such patent. If the patent is held to be valid but limited in scope, the Telephone Company shall thereafter be under no obligation to pay royalties with reference to its utilization of the C. H. T. devices or method of operation held not to be covered by such patent.

8. Hewitt warrants that he has full right to grant the licenses and make the agreements herein set forth, and that he has not made and will not make any agreement in conflict herewith.

9. Hewitt agrees that he will, at any time or times on request of the Telephone Company, execute and deliver to the Telephone Company such further or other instruments as the latter may desire for fully vesting in it the license and rights herein conveyed.

10. It is agreed that the recognition of the validity of patents, arising out of the acceptance of this license, is limited to their validity in connection with C. H. T. devices as herein defined.

11. This agreement and license shall be binding upon and shall inure to the benefit of the parties hereto, and their several successors, legal representatives and

assigns. The Telephone Company's rights hereunder shall not be assignable or transferrable except to an assignee or transferee who shall agree in all respects to be bound by the obligations of the Telephone Company hereunder; and Hewitt agrees that he will cause any assignee or transferee of his rights hereunder or of his patents under which this license is granted, to be bound by all of his obligations as expressed herein.

IN WITNESS WHEREOF, Hewitt has executed this instrument and the Telephone Company has caused this instrument to be executed by its proper officers thereunto duly authorized, on the day and year first above written.

_____

AMERICAN TELEPHONE AND TELEGRAPH COMPANY,

By _____

Attest:

_____

Secretary.

The Cooper Hewitt Electric Company referred to in the preamble of the foregoing license hereby acknowledges and agrees with the American Telephone and Telegraph Company that, so far as concrns itself or others claiming under it, the above-mentioned Peter Cooper Hewitt has full right and power to grant the licenses and to make the agreements set forth in the foregoing instrument, and it hereby, to the same extent, ratifies and confirms the granting of the licenses and the said license agreement.

COOPER HEWITT ELECTRIC COMPANY,
By

Attest:
Secretary.

State of New York, }
County of New York, } ss.:

On this day of , 191 , before me personally came PETER COOPER HEWITT, to me known and known to me to be the individual described in and who executed the foregoing instrument, and he acknowledged to me that he executed the same.

Notary Public.

United States License.

AGREEMENT made this fifteenth day of December, 1913, between PETER COOPER HEWITT, of New York City and the AMERICAN TELEPHONE AND TELEGRAPH COMPANY, a New York corporation, herein called the Telephone Company.

WHEREAS, the said Hewitt has made many inventions, among which are those set forth in the following patents of the United States:

No. 749,791, dated January 19, 1904,
No. 749,792, dated January 19, 1904,
No. 749,793, dated January 19, 1904,
No. 758,650, dated May 3, 1904,
No. 781,001, dated January 31, 1905,
No. 781,002, dated January 31, 1905,
No. 954,434, dated April 12, 1910,
No. 991,304, dated May 2, 1911,

and

WHEREAS, said enumerated patents and other patents for the inventions of said Hewitt were assigned to the Cooper Hewitt Electric Company, a New York corporation, under certain agreements dated March 7, 1900, and November 7, 1902, between the said Hewitt and George Westinghouse, and an agreement, dated December 31, 1912, was entered into between said Hewitt and the Cooper Hewitt Electric Company, a New Jersey corporation (both of the Cooper Hewitt Electric Companies being hereinafter referred to as the Cooper Hewitt Electric Company, the New Jersey Company be-

ing the successor of the New York Company), but the said Hewitt retained under said agreements and now owns, for himself and his assigns, the exclusive rights under all of said patents for certain uses, among which is their use for C. H. T. devices as hereinafter defined; and

WHEREAS, the Telephone Company desires a license to utilize said inventions in such apparatus as hereinafter set forth:

Now, in consideration of the mutual agreements herein contained, it is agreed as follows:

1. Hewitt hereby grants to the Telephone Company the right and license to make or cause to be made for it and to use, in telephone or telegraph systems employing wires or metallic conductors connecting stations, gas or vapor and so called vacuum electric apparatus for creating, transmitting, receiving, relaying, repeating, modifying, amplifying or boosting telephonic or telegraphic electric currents, waves or impulses, or (in so far as not in conflict with the agreements above referred to) for lightning arresters, or strong current discharger or protector, or charge or voltage limiters, embodying or made or operating in accordance with any and all inventions which he has heretofore made either alone or jointly with others (all of which devices are, for convenience, herein called C. H. T. devices), and to sell or lease such C. H. T. devices to others and to license them to sell, use or lease the same, which license shall continue to the end of the terms of all patents of the United States

which have been or may be obtained on inventions which have been made by Hewitt up to the present date for which applications for United States patents shall have been filed prior to two years after the date hereof.

The foregoing licenses are granted and agreed to be granted for and throughout the United States of America and its territories and dependencies, and shall be exclusive (subject to the provisions hereinafter contained) in the field of telephony and telegraphy using wires or metalic conductors connecting stations on land lines, including communications over sub-aqueous cables, such as extend through rivers, lakes and seas, and to the immediate outlying land, and shall be non-exclusive for trans-oceanic cable lines; nothing herein shall prevent Hewitt from granting to others rights under his inventions to use C. H. T. devices in trans-oceanic cable lines at intermediate landing points and terminals, nor from granting to others the right to make C. H. T. devices for such uses.

2. Hewitt further agrees that as and when, up to January, 1921, he hereafter makes inventions, useful in or applicable to C. H. T. devices, he will, upon filing application for patent for any such invention, endeavor to promptly and fully disclose the same to the Telephone Company and deliver to the Telephone Company a copy of such application, and each such invention made by him alone shall come under this agreement (and likewise his interest in those made jointly with others), if the Telephone Company so elects from time to time within

one year after the date of each such disclosure. If the Telephone Company does so elect the Telephone Company shall have, with reference to such inventions, the license above expressed to the end of the terms of the United States patents to be granted upon the several inventions so disclosed and brought under this agreement. If Hewitt or the Cooper Hewitt Electric Company does not desire to file and prosecute applications for United States patents upon any such invention hereafter made, Hewitt shall disclose the same to the Telephone Company, and give the Telephone Company an opportunity of filing and prosecuting the same. If the Telephone Company elects to prosecute the same, Hewitt agrees to execute all proper papers in connection therewith and to assign to the Telephone Company the invention and United States patents to be issued for the same, the Telephone Company agreeing to grant to Hewitt, free of expense, rights under said patents for uses in fields other than those of telephony and telegraphy in a broad sense as defined in the last paragraph of this Clause 2.

The Telephone Company agrees that when and if it makes commercial installations of C. H. T. devices embodying any inventions under which this license is granted, it will, up to January 19, 1921, give to Hewitt, but not to his assigns or representatives, the opportunity of examining the same and witnessing the operation thereof. Information received by Hewitt from or through the Telephone Company or its interests shall be utilized by Hewitt in his discretion in the interest of the Telephone Company and not to the detriment of that Company.

The Telephone Company further agrees that it will give to Hewitt, but not to his assigns or representatives, an opportunity of acquiring a right to make, use and sell, and of granting to others the right to make, use and sell any improvements which the Telephone Company may make in C. H. T. devices embodying inventions under which this license is granted, such rights being limited, however, to manufacture, sale and use for other than telephony or telegraphy in a broad sense, which "broad sense" here includes transmission over conductors on land and trans-oceanic cables and wireless transmission. Such rights may be acquired by Hewitt on terms to be agreed upon from time to time; it is recognized that no basis for such acquisition can be fixed at present; but the understanding is that Hewitt shall have an opportunity of acquiring such rights or of purchasing such apparatus from the Telephone Company at a fair price, and at a price at least as low as any price, acceptable to the Telephone Company, offered by others.

3. The Telephone Company agrees that it will keep books showing the manufacture, lease and sale of said C. H. T. devices by or for it, and the installations of such apparatus made by it or under its authority, which books shall at all reasonable times be open to the inspection of Hewitt or his duly authorized agents.

An "installation" is defined as an apparatus employed to create, transmit, receive, relay, repeat, modify, amplify or boost electric currents, waves or impulses in a circuit or between lines connected or interconnected to form a circuit for transmission or sounds or signals, whether a one-way or two-way working apparatus, and without regard to the number of tubes employed or the

particular circuit arrangement or connections, or employed as a lightning arrester, or strong current discharger or protector, or charge or voltage limiter in telephone or telegraph systems, provided, however, that

(a) if the apparatus employed in a given connection or circuit is located at two or more places separated by outside line construction, the apparatus in each such location shall be counted as a separate installation;

(b) if a circuit divides into several branches not re-uniting, and independent apparatus is installed in more than one branch of the circuit, then each such apparatus shall count as a separate installation, even although not separated from the others by outside line construction;

(c) if there should be employed apparatus capable of operating simultaneously for several independent circuits, although using one or more parts in common, such apparatus shall be considered as a number of installations equal to the number of independent circuits upon which it is arranged to work simultaneously.

4. The Telephone Company agrees that it will, on or before the twentieth day of each January and July, during the term of this agreement, render to Hewitt a statement in writing setting forth the number of installations of C. H. T. devices (embodying or operating in accordance with the inventions of any unexpired patent or patents under which this license is granted,

and in force at the time of each such installation), leased, sold or put into use by it or under its authority in the six calendar months immediately preceding that in which each such statement is rendered.

The Telephone Company further agrees that, subject to the provisions hereinafter contained, it will, at the time of rendering each such statement, pay to Hewitt an amount in royalties to be computed in accordance with Schedule A hereto attached, for each such installation so reported.

Each sale of C. H. T. devices for an installation shall, for the purpose of royalty payments, be considered to be an installation whether or not actually installed at time of sale and royalty shall then accrue.

Royalties are payable only with reference to installations as above defined and not on tubes or other parts for replacement or renewal, nor upon the same apparatus when transferred to a new location or to other circuits.

5. If the royalties paid under this license with reference to the year 1914 and each year thereafter up to and including 1920 do not amount to at least as much as Ten Thousand Dollars ($10,000) for each year, and the Telephone Company does not, at the time of rendering the statement for the last half of any such year, pay an amount which, added to the royalties when due, brings the total payments for the year up to said sum, Hewitt may, by notice in writing delivered to the Telephone Company on or before March 1 of the year fol-

lowing that for which the payments have been less than said sum, change the exclusive license, herein granted, to a non-exclusive one.

6. If the Telephone Company fails to render statements and pay the royalties due as and when stated above, and fails to repair its default within sixty days after the receipt of written notice thereof from Hewitt, Hewitt may cancel and terminate this agreement by serving on the Telephone Company written notice of his election so to do.

7. In case at any time or times, during the continuance of this license, any of the patents under which this license is granted, are being infringed by the use of apparatus within the field of telegraphy and telephony covered by this license, then the Telephone Company shall have the right to cause a suit or suits for infringement to be brought and prosecuted under such patent at its own cost and expense using the name of Hewitt or the Cooper Hewitt Electric Company, or both, if it so desires. If the attorneys employed by the Telephone Company for prosecuting this suit shall be unsatisfactory to the said Hewitt or to the Cooper Hewitt Electric Company, in case the latter has an interest in such patent, he or it may employ an attorney to take part in the prosecution of the case.

If any patent with reference to which royalty is payable hereunder is held to be invalid by any Court of final jurisdiction or by any inferior Court from whose decree no appeal is taken and prosecuted within the time

prescribed by law, the Telephone Company shall thereafter be under no obligation to pay royalties with reference to such patent. If the patent is held to be valid but limited in scope, the Telephone Company shall thereafter be under no obligation to pay royalties under that patent, with reference to its utilization of the C. H. T. devices or method of operation held not to be covered by such patent.

8. Hewitt warrants that he has full right to grant the licenses and make the agreements herein set forth, and that he has not made and will not make any agreement in conflict herewith.

9. Hewitt agrees that he will, at any time or times on request of the Telephone Company, execute and deliver to the Telephone Company such further or other instruments as the latter may desire for fully vesting in it the license and rights herein conveyed.

10. It is agreed that the recognition of the validity of patents, arising out of the acceptance of this license, is limited to their validity in connection with C. H. T. devices as herein defined.

11. This agreement and license shall be binding upon and shall inure to the benefit of the parties hereto, and their several successors, legal representatives and assigns, except as otherwise specifically stated in this agreement. The Telephone Company's rights hereunder shall not be assignable or transferable except to an assignee or transferee who shall agree in all respects

to be bound by the obligations of the Telephone Company hereunder; and Hewitt agrees that he will cause any assignee or transferee of his rights hereunder or of his patents under which this license is granted, to be bound by all of his obligations as expressed herein.

IN WITNESS WHEREOF, Hewitt has executed this instrument and the Telephone Company has caused this instrument to be executed by its proper officers thereunto duly authorized, on the day and year first above written.

(Signed) PETER COOPER HEWITT.

Witnesses:
CHARLES A. TERRY,
CHARLES B. HILL.

AMERICAN TELEPHONE AND TELEGRAPH COMPANY,
By (Signed) H. B. THAYER,
Vice-President.

Attest:
(Signed) ALFRED E. HOLCOMB,
Assistant Secretary.
(Seal)

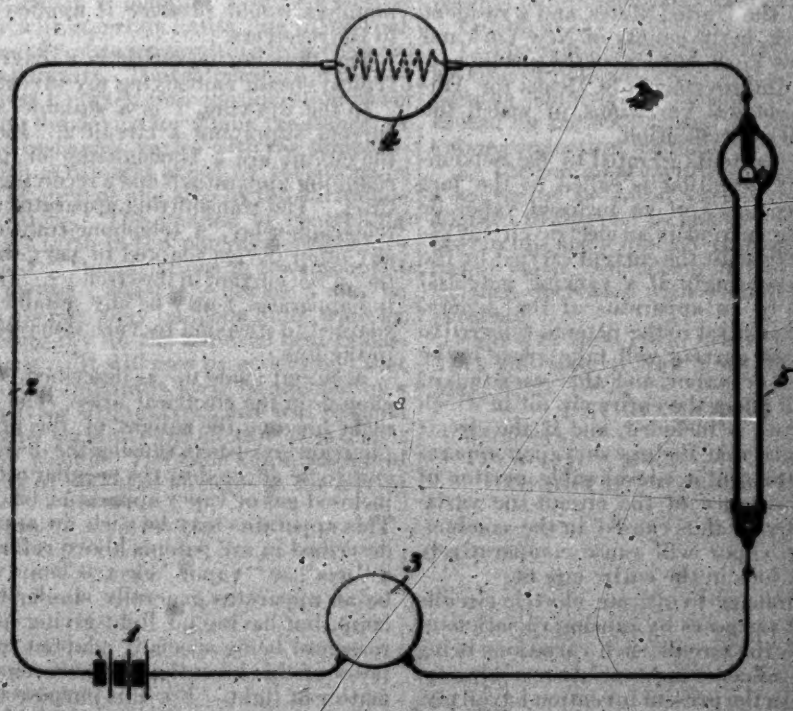
PLAINTIFF'S EXHIBIT No. 202.

No. 781,001. PATENTED JAN. 31, 1905.

P. C. HEWITT.

MEANS FOR AMPLIFYING ELECTRICAL VARIATIONS.

APPLICATION FILED MAY 18, 1903.



Witnesses
Frank L. Ober
Chas. H. Stinchfield Jr.

Inventor
Peter Cooper Hewitt
By his Attorney
Chandlee & Terry

No. 781,001. Patented January 31, 1905.

UNITED STATES PATENT OFFICE.

PETER COOPER HEWITT, OF NEW YORK, N. Y., ASSIGNOR, BY MESNE ASSIGNMENTS, TO COOPER HEWITT ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

MEANS FOR AMPLIFYING ELECTRICAL VARIATIONS.

SPECIFICATION forming part of Letters Patent No. 781,001, dated January 31, 1905.

Application filed May 16, 1902. Serial No. 107,604.

To all whom it may concern:

Be it known that I, PETER COOPER HEWITT, a citizen of the United States, and a resident of New York, in the county of New York and State of New York, have invented certain new and useful Improvements in Means for Amplifying Electrical Variations, of which the following is a specification.

In certain patents granted to me September 17, 1901, attention is called to the fact that the resistance of an inclosed vapor or gas carrying current in an electric circuit varies inversely with the current carried by the vapor. Accordingly if a varying potential be applied to an apparatus of the general character described in the patents referred to a variation of current will take place in the inclosed gas or vapor, and this variation of current will affect the entire circuit in which the apparatus is included, and if the circuit is so arranged that the gas or vapor apparatus shall represent a considerable portion of the total resistance of the circuit the variations of current thus caused in the conducting gas or vapor will cause comparatively large variations in the entire circuit.

It is customary to operate electric circuits for various purposes by causing variations of potential in the circuit, such variations being utilized to influence appropriate receiving apparatus. In the present invention I avail myself of the peculiar features of electrical resistance in a gas or vapor conductor to vary or magnify the effects produced by potential variations in a circuit. By virtue of the described characteristics of gas or vapor conductors it is possible, for instance, to translate variations of potential in a circuit into variations of current or quantity, and inasmuch as the conducting gas or vapor responds practically instantaneously to the applied variations of potential, currents of any practical rapidity or frequency can be made to undergo the described transformation and produce their effects upon a suitable receiving apparatus. As the practical result of an increase of applied potential is an increased flow of current, the original electrical impulses in the circuit may produce magnified effects as compared with those which the same impulses would produce if applied directly to the receivers.

The drawing herewith is a diagram of a typical circuit embodying my invention.

In the drawing, 1 is a suitable source of current supplying a circuit 2. Included in the circuit are a transmitting or potential-changing apparatus 3 and a receiving apparatus 4. The transmitting apparatus may be a telegraph-relay, a telephone-transmitter, or any other device adapted to vary the potential of the current in the circuit 2. The receiving apparatus 4 may be any suitable receiver adapted to respond to variations of current in the line.

A circuit made up as described is common enough in the electrical arts. The improvement forming the subject of the present application consists in causing the described circuit to be affected by the peculiar action of an inclosed gas or vapor apparatus, (shown at 5.) This apparatus may be such an apparatus as described in my patents above referred to as a "gas" or "vapor" electric lamp, or it may be an apparatus generally similar to such a lamp, but having no light-giving quality by reason of being specially adapted to the purposes of this invention without regard to the matter of light. For this purpose the device may be made with a comparatively short gas or vapor path and having such cross-section that with the current normally traversing it the vapor or gas may become but faintly luminous. The resistance of the circuit outside the device 5 is practically constant except for the slight variations introduced through the instrumentality of the potential-changing apparatus 3. As the resistance of the device 5 varies substantially inversely with the quantity of the current flowing, or, to put it another way, requires a definite voltage to pass a definite current therethrough, any diminution, for instance, of the potential applied to its terminals by reason of an increase of resistance on the part of the device 3 will result in not only the diminution of flow of current due to the

increased resistance of the device 3, but also to an additional diminution due to the change brought about in the device 5 by the decreased current resulting from the decreased potential at the terminals of the device 5. Likewise an increase of potential at the terminals of the device 5, due to a change of resistance in the outside circuit, will cause an increase of current-flow therethrough greatly in excess of the change due to the change of resistance in the other portions of the circuit. In other words, the changes of resistance in other portions of the circuit than the device 5 bring about such variations of conditions in the device 5 as to augment the variations of current-flow through the entire circuit. It should be borne in mind, however, that the resistance of the other portions of the circuit than the device 5 serves in a measure as a balancing resistance for the device 5; otherwise a decrease of resistance in the external circuit might result in a continuing unchecked decrease of the total resistance of the circuit including the device 5. The device 5 itself, however, has in a measure a self-corrective tendency within certain limits, due to internal variations of resistance resulting from changes in its temperature. The temperature of the device 5 must be taken into consideration when measuring the device for ohmic resistance, as its ohmic resistance varies with the temperature which is brought about by variations in the flow of current and also by the surrounding conditions. The method of controlling these is set forth in the patents hereinbefore referred to. The variations in the amount of current through which the device 5 may be made to operate may be made quite wide by constructing it with the required heat-radiating capacity. It will now be understood that the receiving apparatus 4 will be affected by a comparatively large current and will respond with greater certainty and effectiveness than it otherwise would. The same amplification of the effects of potential changes in the circuit takes place whatever be the degree of potential increase or variation.

When the resistance of the element 5 is made a considerable portion of the total resistance of the circuit, the effect of the changes of resistance in the element named will be very marked, especially when the source of supply is great.

By reason of the gaseous condition of the conducting medium employed the gas or vapor apparatus responds instantly to potential changes in the current without essential loss of energy. In this respect it differs from other materials or substances, because in such other materials or substances work has to be done in the process of reducing the resistance whereby a loss of energy is caused and the time element becomes a considerable factor, while in my apparatus the amount of material so affected is so small that the energy required to produce the result may be practically neglected.

Means for starting the flow of current through the apparatus are set forth in the patents hereinbefore referred to.

I claim as my invention—

1. The combination in an electric circuit, of a source of potential variation, a receiving apparatus adapted to translate the variations caused by the source, and an inclosed gas or vapor conducting medium.

2. The combination in an electric circuit, of a source of potential variations, a receiver adapted to respond to changes of current in the circuit, and a quickly-responding inclosed gas or vapor conducting medium whose resistance decreases with increments of temperature.

Signed at New York, in the county of New York and State of New York, this 9th day of May, A. D. 1902.

PETER COOPER HEWITT.

Witnesses:
WM. H. CAPEL,
GEORGE H. STOCKBRIDGE.

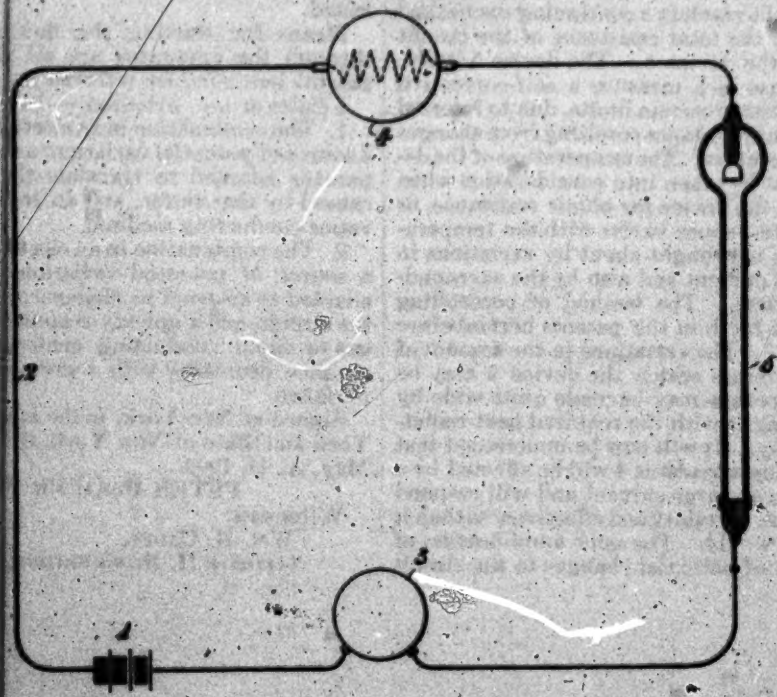
PLAINTIFF'S EXHIBIT No. 203.

No. 781,002. PATENTED JAN. 31, 1905.

P. C. HEWITT.

METHOD OF AMPLIFYING ELECTRICAL VARIATIONS.

APPLICATION FILED MAY 18, 1903.



Witnesses
Frank L. Otis
Geo. H. Beckley

Inventor
Peter Cooper Hewitt
By his Attorneys
Charles A. Terry

No. 781,002. Patented January 31, 1905.

UNITED STATES PATENT OFFICE.

PETER COOPER HEWITT, OF NEW YORK, N. Y., ASSIGNOR, BY MESNE ASSIGNMENTS, TO COOPER HEWITT ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

METHOD OF AMPLIFYING ELECTRICAL VARIATIONS.

SPECIFICATION forming part of Letters Patent No. 781,002, dated January 31, 1905.

Application filed May 15, 1903. Serial No. 157,282.

To all whom it may concern:

Be it known that I, PETER COOPER HEWITT, a citizen of the United States, and a resident of New York, in the county of New York and State of New York, have invented certain new and useful Improvements in Methods of Amplifying Electrical Variations, of which the following is a specification.

In certain patents granted to me September 17, 1901, notably in the patents numbered 682,695, 682,696, and 682,697, attention is called to the fact that the resistance of an inclosed vapor or gas carrying current in an electric circuit varies inversely with the current carried by the vapor. Accordingly if a varying potential be applied to an apparatus of the general character described in the patents referred to a variation of current will take place in the inclosed gas or vapor, and this variation of current will affect the entire circuit in which the apparatus is included, and if the circuit is so arranged that the gas or vapor apparatus shall represent a considerable portion of the total resistance of the circuit the variations of current thus caused in the conducting gas or vapor will cause comparatively large variations in the entire circuit.

It is customary to operate electric circuits for various purposes by causing variations of potential in the circuit, such variations being utilized to influence appropriate receiving apparatus. In the present invention I avail myself of the peculiar features of electrical resistance of a gas or vapor conductor to vary or magnify the effects produced by potential variations in a circuit.

By virtue of the described characteristics of gas or vapor conductors it is impossible, for instance, to translate variations of potential in a circuit into variations of current or quantity, and inasmuch as the conducting gas or vapor responds practically instantaneously to the applied variations of potential currents of any practical rapidity or frequency can be made to undergo the described transformation and produce their effects upon a suitable receiving apparatus. As the practical result of an increase of applied potential is an increased flow of current, the original electrical impulses in the circuit may produce magnified effects as compared with those which the same impulses would produce if applied directly to the receivers.

The drawing herewith is a diagram of a typical circuit embodying my invention.

In the drawing, 1 is a suitable source of current supplying a circuit 2. Included in the circuit are a transmitting or potential changing apparatus 3 and a receiving apparatus 4. The transmitting apparatus may be a telegraph-relay, a telephone-transmitter, or any other device adapted to vary the potential of the current in the circuit 2. The receiving apparatus 4 may be any suitable receiver adapted to respond to variations of current in the line.

A circuit made up as described is common enough in the electrical arts.

The improvement forming the subject of the present application consists in causing the described circuit to be affected by the peculiar action of an inclosed gas or vapor apparatus, (shown at 5.) This apparatus may be such an apparatus as described in my patents above referred to as a "gas" or "vapor" electric lamp, or it may be an apparatus generally similar to such a lamp, but having no light-giving quality by reason of being specially adapted to the purposes of this invention without regard to the matter of light. For this purpose the device may be made with a comparatively short gas or vapor path and having such cross-section that with the current normally traversing it the vapor or gas may become but faintly luminous. The resistance of the circuit outside the device 5 is practically constant except for the slight variations introduced through the instrumentality of the potential-changing apparatus 3. As the resistance of the device 5 varies substantially inversely with the quantity of the current flowing, or, to put it another way, requires a definite voltage to pass a definite current therethrough, any diminution, for instance, of the potential applied to its terminals by reason of an increase of resistance on the part of the de-

vice 5 will result in not only the diminution of flow of current due to the increased resistance of the device, but also to an additional diminution due to the change brought about in the device 5 by the decreased current resulting from the decreased potential at the terminals of the device 5. Likewise an increase of potential at the terminals of the device 5 due to a change of resistance in the outside circuit will cause an increase of current-flow therethrough greatly in excess of the change due to the change of resistance in the other portions of the circuit. In other words, the changes of resistance in other portions of the circuit than the device 5 bring about such variations of conditions in the device 5 as to augment the variations of current-flow through the entire circuit. It should be borne in mind, however, that the resistance of the other portions of the circuit than the device 5 serves in a measure as a balancing resistance for the device 5. Otherwise a decrease of resistance in the external circuit might result in a continuing unchecked decrease of the total resistance of the circuit including the device 5. The device 5 itself, however, has in a measure a self-corrective tendency within certain limits due to internal variations of resistance resulting from changes in its temperature. The temperature of the device 5 must be taken into consideration when measuring the device for ohmic resistance, as its ohmic resistance varies with the temperature which is brought about by variations in the flow of current and also by the surrounding conditions. The method of controlling these is set forth in the patents hereinbefore referred to. The variations in the amount of current through which the device 5 may be made to operate may be made quite wide by constructing it with the required heat-radiating capacity.

It will now be understood that the receiving apparatus 4 will be affected by a comparatively large current and will respond with greater certainty and effectiveness than it otherwise would.

The same amplification of the effects of potential changes in the circuit takes place whatever be the degree of potential increase or variation.

When the resistance of the element 5 is made a considerable portion of the total resistance of the circuit, the effect of the changes of resistance in the element named will be very marked, especially when the source of supply is great.

By reason of the gaseous condition of the conducting medium employed the gas or vapor apparatus responds instantly to potential changes in the current without essential loss of energy. In this respect it differs from other materials or substances, because in such other materials or substances work has to be done in the process of reducing the resistance, whereby a loss of energy is caused and the time element becomes a considerable factor, while in my apparatus the amount of material so affected is so small that the energy required to produce the result may be practically neglected.

Means for starting the flow of current through the apparatus are set forth in the patents hereinbefore referred to.

I claim as my invention—

1. The method of amplifying potential variations caused in an electric circuit, which consists in applying the said variations to a quickly-responding medium in the circuit, thereby causing a change in current-flow through such medium, and by such change of current-flow producing in such medium a change of specific resistance resulting in a still further change in current-flow through the circuit.

2. The method of amplifying energy variations caused in an electric circuit of which an inclosed gas or vapor forms part, and of translating the effects of such amplified variations, which consists in affecting the conducting gas or vapor by variations of current, transforming such variations of current into variations of resistance, and applying such currents to a suitable translating device.

3. The method of amplifying energy variations caused in an electric circuit including an inclosed conducting gas or vapor and electrodes therefor, which consists in affecting the conducting gas or vapor by variations of current, and thereby transforming such variations into corresponding amplified variations of current.

Signed at New York, in the county of New York and State of New York, this 9th day of May, A. D. 1902.

PETER COOPER HEWITT.

Witnesses:
WM. H. CAPEL,
GEORGE H. STOCKBRIDGE.

PLAINTIFF'S EXHIBIT No. 204.

No. 749,791. PATENTED JAN. 19, 1904.

P. C. HEWITT.

MEANS FOR REPRODUCING ELECTRICAL VARIATIONS.

APPLICATION FILED MAY 16, 1902.

NO MODEL.

Fig. 1.

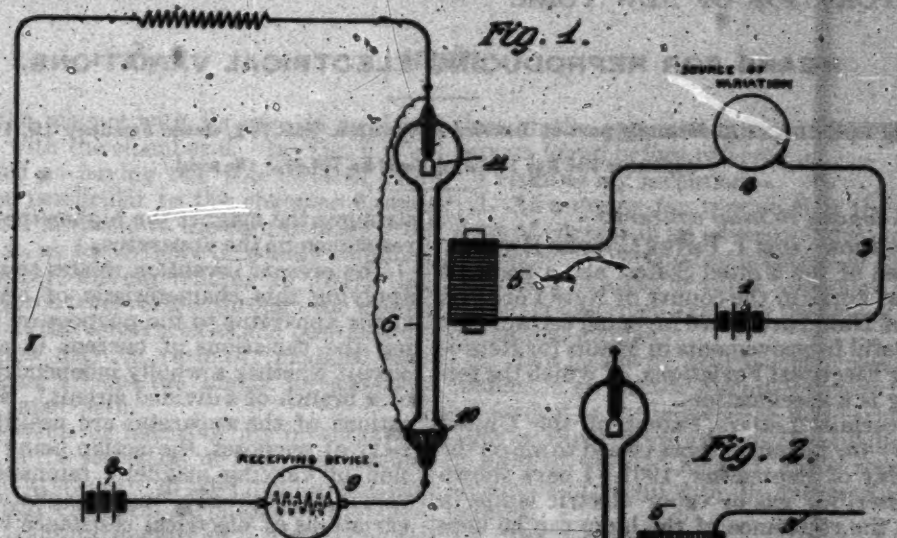


Fig. 2.

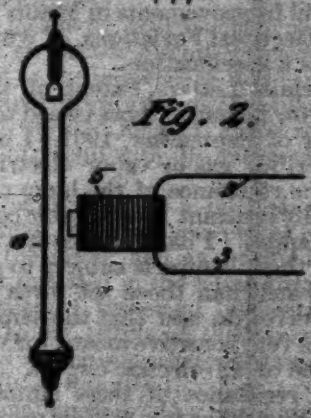
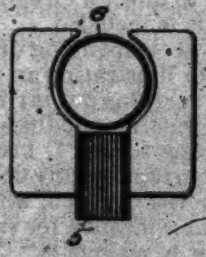


Fig. 3.



Witnesses
Thos. L. Oberly
Geo. H. Strong

Inventor
Peter Cooper Hewitt.
By his Attorney
Charles A. Brown

No. 749,701. Patented January 19, 1904.

UNITED STATES PATENT OFFICE.

PETER COOPER HEWITT, OF NEW YORK, N. Y., ASSIGNOR, BY MESNE ASSIGNMENTS, TO COOPER HEWITT ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

MEANS FOR REPRODUCING ELECTRICAL VARIATIONS.

SPECIFICATION forming part of Letters Patent No. 749,701, dated January 19, 1904.

Application filed May 16, 1902. Serial No. 107,601. (No model.)

To all whom it may concern:

Be it known that I, PETER COOPER HEWITT, a citizen of the United States, and a resident of New York, in the county of New York and State of New York, have invented certain new and useful Improvements in Means for Reproducing Electrical Variations, of which the following is a specification.

In certain Letters Patent of the United States—for instance, those issued to me on the 17th day of September, 1901—I have shown and described gas or vapor electric lamps in which the resistance of the lamp can be kept practically constant by a suitable construction of the lamps. I have found that the resistance of these lamps is subject to control by other means than those set forth in the patents referred to and that the lamps may be used as a very sensitive means for varying the resistance of an electric circuit. For example, the resistance of these lamps is readily affected by a magnetic field in proximity to it and the variations in the field may be made to reproduce themselves as a varying electrical resistance in the lamp. The same effect is produced by a magnet or solenoid upon an apparatus of this general character whether the apparatus is designed to operate as a lamp or light-giving medium or is especially designed as a means of varying the current in a circuit. In other words, in applying the described apparatus to the purposes of this invention I may so construct it as to make it capable of giving light, or I may prefer to inclose an appropriate gas or vapor in a container so proportioned as to accomplish the special results aimed at by this invention irrespective of whether the apparatus is then designed to produce light or not.

In order to produce the desired variations of resistance in the gas or vapor apparatus, I generally locate the magnet or solenoid at the side of the apparatus where it will distort the current passing between the positive and the negative electrodes, it being found that the active current in an apparatus of this sort tends to be deflected by a magnetic field. The stronger the magnet the higher the electrical resistance of the apparatus.

The present invention relates to means for applying this characteristic of my lamp or vapor apparatus to the purpose of reproducing the variations of current in an electric circuit whether a wholly independent circuit or a branch of a divided circuit. Such applications of the apparatus are useful for a variety of purposes, the action being a conversion of varying magnetic intensities due to varying current affecting a magnetic field into variations of electrical resistance which may be made to affect a circuit in which my vapor apparatus is included.

In the accompanying drawings, Figure 1 is a diagram illustrating an organization of circuits for carrying out my invention, and Figs. 2 and 3 illustrate modifications.

Referring to Fig. 1, 1 represents a source of electric currents of any desired character connected in the circuit 3, which is provided with any suitable means 4 for varying the magnetic effects in a magnet 5. The magnet 5 is so placed with reference to a chamber 6, containing a conducting gas or vapor, which in turn is connected in a circuit 7, provided with any suitable source 8 of electric currents. The variations in the flow of current through the circuit 7 may be caused to act upon a receiving device 9 of any desired character. The means for varying the magnetic effects in the magnet 5 may, for example, be a telephone-transmitter, and the receiving device 9 may be a telephone-receiver. The gas or vapor within the tube or container is of any appropriate character, as more fully set forth in my patents hereinbefore referred to, and the negative electrode 10 may be of mercury or of any other suitable means for receiving the current from the gas or vapor and likewise the positive electrode 11, although for convenience I have in the drawings indicated it as being of a solid material held within the chamber 6.

The location of the magnet 5 and its particular relation to the chamber 6 may be variously modified. In Fig. 1 I have repre-

sented the magnet with its core in a plane parallel with the chamber 6. In Fig. 2 it is illustrated as having one pole directed in a plane perpendicular to the chamber 6, and in Fig. 3 I have shown the core as being prolonged, so as to partially or wholly embrace the chamber, thereby tending to direct the lines of force transversely through the gas or vapor; but the constructions and positions of the magnet may be variously modified, the object being to cause the lines of force to pass into the vapor-path.

It is possible by means of my invention to produce in the secondary or receiving circuit electrical variations of greater magnitude than the original electrical variations of the primary or transmitting circuit. This is due to the fact that a given magnetic variation may cause a wider fluctuation of effective resistance in the gas or vapor than the fluctuations of electrical energy producing the variation of the magnetic field of force. Accordingly by employing one of my lamps or vapor apparatuses, as described, I may magnify the vibrations of the circuit not by inductive effects, but by varying the ohmic resistance of the circuit in which the apparatus is included.

I have mentioned a telephone-circuit merely for purposes of illustration. The amplifications due to changes in resistance of my apparatus may be applied to other circuits as well, including circuits carrying currents of large quantity.

It will further be understood that the applications of my invention are not limited to cases where it is desired to amplify the primary variations, but are useful also where it is merely desired to reproduce them in the same or even less magnitude.

Means for starting the flow of current through the apparatus are set forth in the patents hereinbefore referred to.

I claim as my invention—

1. As a means for reproducing the variations of current in an electric circuit, an electromagnet subject to the influence of said variations, and a gas or vapor apparatus of the character described located in the field of force of the said magnet.

2. As a means for reproducing current variations in an electric circuit, an electromagnet subject to the influence of said variations, a gas or vapor apparatus located in the field of force of the said magnet, and a receiving apparatus in circuit with the gas or vapor apparatus.

3. The combination of a telephonic transmitting-circuit, a telephone-receiver, a circuit including the latter, and an inclosed gas or vapor path included in the latter circuit, and an electromagnet traversed by electric currents due to the effects of the transmitting-circuit, and acting upon the gas or vapor path substantially as described.

4. The combination with a telephonic transmitting-circuit, an electromagnet included therein, a telephonic receiving-circuit having an inclosed gas or vapor path inserted therein, the gas or vapor path and the electromagnet occupying such relative positions that a portion at least of the lines of force from the electromagnet act upon the gas or vapor path.

Signed at New York, in the county of New York and State of New York, this 9th day of May, A. D. 1902.

PETER COOPER HEWITT.

Witnesses:
WM. H. CAPEL,
GEORGE H. STOCKBRIDGE.

PLAINTIFF'S EXHIBIT No. 205.

No. 749,792. PATENTED JAN. 19, 1904

P. C. HEWITT.

METHOD OF REPRODUCING ELECTRICAL VARIATIONS.

APPLICATION FILED MAY 16, 1902.

NO MODEL.

Fig. 1.

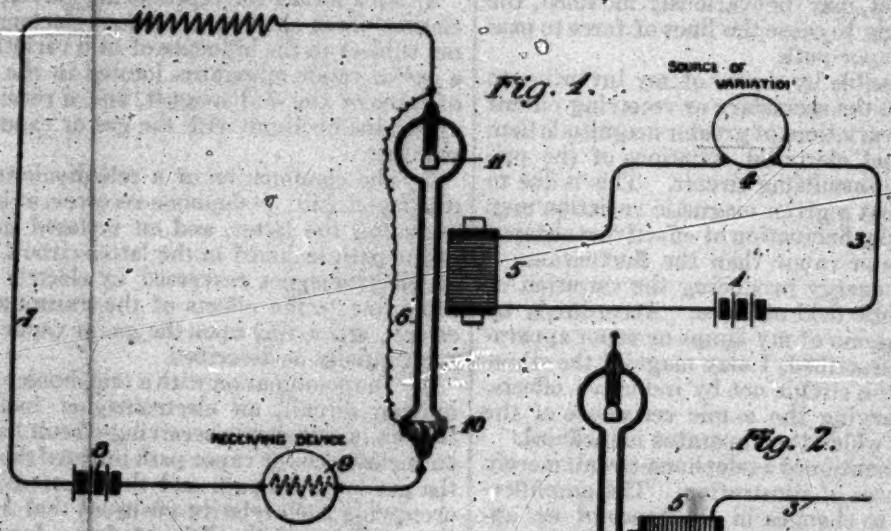


Fig. 2.

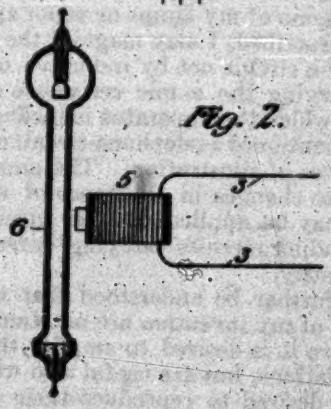


Fig. 3.

Witnesses
Thad. A. Otis
Geo. H. Strong

Inventor
Peter Cooper Hewitt.
By his Attorney
Charles A. Terry

No. 749,702. Patented January 19, 1904.

UNITED STATES PATENT OFFICE.

PETER COOPER HEWITT, OF NEW YORK, N. Y., ASSIGNOR, BY MESNE ASSIGNMENTS, TO COOPER HEWITT ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

METHOD OF REPRODUCING ELECTRICAL VARIATIONS.

SPECIFICATION forming part of Letters Patent No. 749,702, dated January 19, 1904.

Application filed May 16, 1903. Serial No. 157,502. (No model.)

To all whom it may concern:

Be it known that I, PETER COOPER HEWITT, a citizen of the United States, and a resident of New York, in the county of New York and State of New York, have invented certain new and useful Improvements in Methods of Reproducing Electrical Variations, of which the following is a specification.

In certain Letters Patent of the United States—for instance, those issued to me on the 17th day of September, 1901—I have shown and described gas or vapor electric lamps in which the resistance of the lamp can be kept practically constant by a suitable construction of the lamps. I have found that the resistance of these lamps is subject to control by other means than those set forth in the patents referred to and that the lamps may be used as a very sensitive means for varying the resistance of an electric circuit. For example, the resistance of these lamps is readily affected by a magnetic field in proximity to it, and the variations in the field may be made to reproduce themselves as a varying electrical resistance in the lamp. The same effect is produced by a magnet or solenoid upon an apparatus of this general character whether the apparatus is designed to operate as a lamp or light-giving medium or is especially designed as a means of varying the current in a circuit. In other words, in applying the described apparatus to the purposes of this invention I may so construct it as to make it capable of giving light, or I may prefer to inclose an appropriate gas or vapor in a container so proportioned as to accomplish the special results aimed at by this invention irrespective of whether the apparatus is then designed to produce light or not. In order to produce the desired variations of resistance in the gas or vapor apparatus, I generally locate the magnet or solenoid at the side of the apparatus, where it will distort the current passing between the positive and the negative electrodes, it being found that the active current in an apparatus of this sort tends to be deflected by a magnetic field. The stronger the magnet the higher the electrical resistance of the apparatus. The present invention relates to means for applying this characteristic of my lamp or vapor apparatus to the purpose of reproducing the variations of current in an electric circuit whether a wholly independent circuit or a branch of a divided circuit. Such applications of the apparatus are useful for a variety of purposes, the action being a conversion of varying magnetic intensities, due to varying current affecting a magnetic field into variations of electrical resistance which may be made to affect a circuit in which my vapor apparatus is included.

In the accompanying drawings, Figure 1 is a diagram illustrating an organization of circuits for carrying out my invention, and Figs. 2 and 3 illustrate modifications.

Referring to Fig. 1, 1 represents a source of electric currents of any desired character connected in the circuit 3, which is provided with any suitable means 4 for varying the magnetic effects in a magnet 5. The magnet 5 is so placed with reference to a chamber 6, containing a conducting gas or vapor, which in turn is connected in a circuit 7, provided with any suitable source 8 of electric currents. The variations in the flow of current through the circuit 7 may be caused to act upon a receiving device 9 of any desired character. The means for varying the magnetic effects in the magnet 5 may, for example, be a telephone-transmitter, and the receiving device 9 may be a telephone-receiver. The gas or vapor within the tube or container is of any appropriate character, as more fully set forth in my patents hereinbefore referred to, and the negative electrode 10 may be of mercury or of any other suitable means for receiving the current from the gas or vapor and likewise the positive electrode 11, although for convenience I have in the drawings indicated it as being of a solid material held within the chamber 6. The location of the magnet 5 and its particular relation to the chamber 6 may be variously modified. In Fig. 1 I have represented the magnet with its core in a plane parallel with the chamber 6. In Fig. 2 it is illustrated as having one pole directed in a plane perpen-

dicular to the chamber 6, and in Fig. 3 I have shown the core as being prolonged, so as to partially or wholly embrace the chamber, thereby tending to direct the lines of force transversely through the gas or vapor; but the constructions and positions of the magnet may be variously modified, the object being to cause the lines of force to pass into the vapor-path.

It is possible by means of my invention to produce in the secondary or receiving-circuit electrical variations of greater magnitude than the original electrical variations of the primary or transmitting circuit. This is due to the fact that a given magnetic variation may cause a wider fluctuation of effective resistance in the gas or vapor than the fluctuations of electrical energy producing the variation of the magnetic field of force. Accordingly by employing one of my lamps or vapor apparatuses as described I may magnify the vibrations of the circuit not by inductive effects but by varying the ohmic resistance of the circuit in which the apparatus is included.

I have mentioned a telephone-circuit merely for purposes of illustration. The amplifications due to changes in resistance of my apparatus may be applied to other circuits as well, including circuits carrying currents of large quantity. It will further be understood that the application of my invention is not limited to cases where it is desired to amplify the primary variations, but is useful also where it is merely desired to reproduce them in the same or even less magnitude.

Means for starting the flow of current through the apparatus are set forth in the patents hereinbefore referred to.

I claim as my invention—

1. The method of reprodnoing current variations in an electrical circuit, which consists in transforming these variations into a varying field of force, causing the said field of force to act magnetically upon an inclosed gas or vapor so as to produce variations of electrical resistance in another circuit.

2. The method of producing in a circuit containing an inclosed conducting gas or vapor, variations of electrical resistance corresponding to variations of current in another circuit, which consists in causing the variations of current in the second-named circuit to act magnetically upon the said gas or vapor and thereby vary the electrical resistance thereof and of the circuit.

3. The method of reproducing in a translating device included in a circuit containing an inclosed gas or vapor path, effects corresponding to electrical variations in another circuit, which consists in converting said electrical variations into magnetic variations, and causing such magnetic variations to act upon an inclosed gas or vapor path, thereby producing variations in the current-flow of the first-named circuit.

4. The method of reproducing in a translating device included in a circuit containing an inclosed gas or vapor, effects corresponding to variations of electrical resistance in another circuit, which consists in causing in the last-named circuit variations of current adapted to affect the translating device, converting these variations of current into magnetic variations, and causing such magnetic variations to act upon the inclosed gas or vapor.

Signed at New York, in the county of New York and State of New York, this 9th day of May, A. D. 1902.

PETER COOPER HEWITT.

Witnesses:

WM. H. CAPEL,

GEORGE H. STOCKBRIDGE.

PLAINTIFF'S EXHIBIT No. 206.

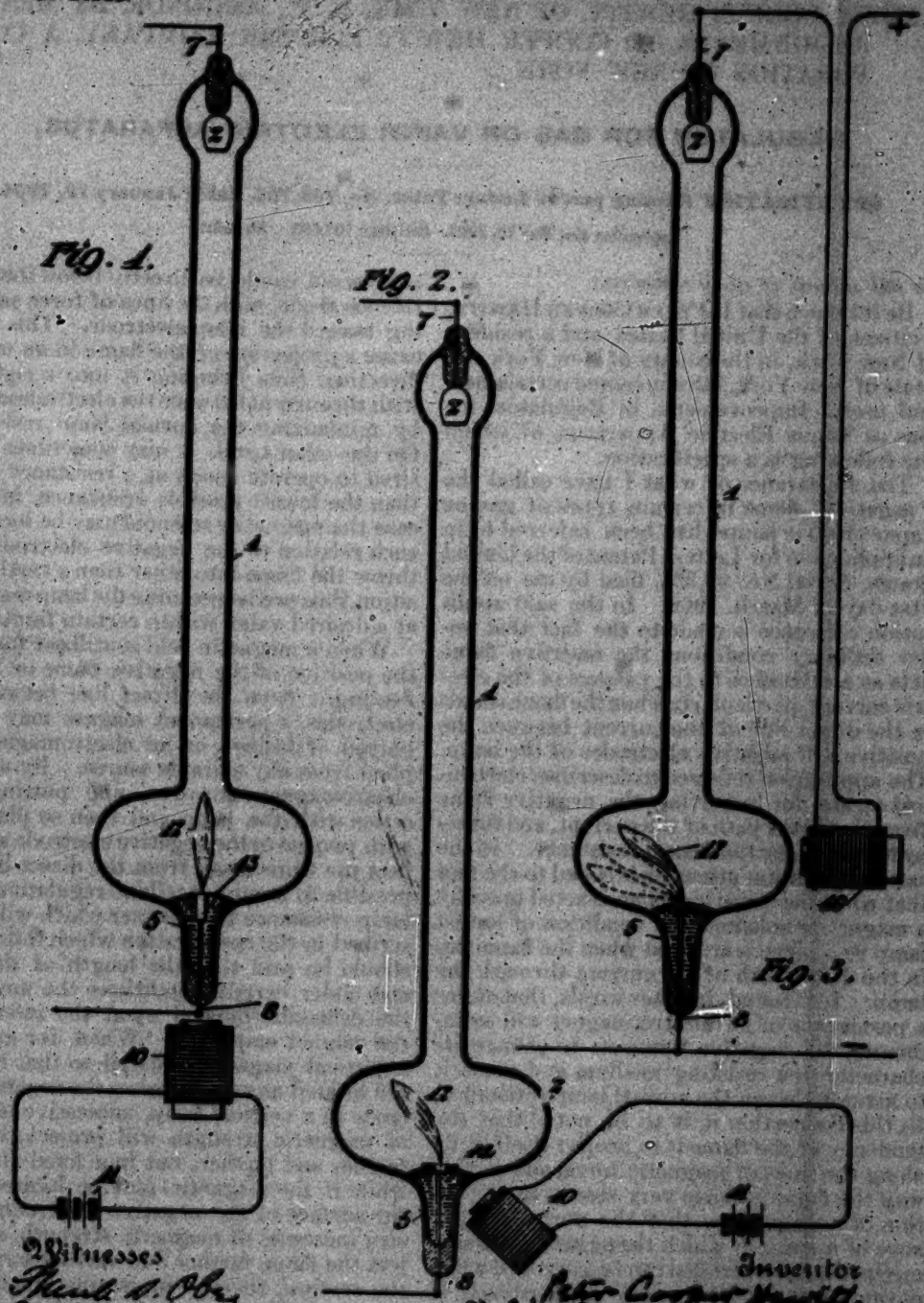
No. 749,793. PATENTED JAN. 19, 1904.

P. C. HEWITT.

REGULATOR FOR GAS OR VAPOR ELECTRIC APPARATUS.

APPLICATION FILED MAY 18, 1903.

NO MODEL.



Witnesses
Frank A. Ober
Geo. H. Strong Jr.

Inventor
Peter Cooper Hewitt.
By his Attorney
Charles A. Terry

No. 749,793. Patented January 19, 1904.

UNITED STATES PATENT OFFICE.

PETER COOPER HEWITT, OF NEW YORK, N. Y., ASSIGNOR, BY MESNE ASSIGNMENTS, TO COOPER HEWITT ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

REGULATOR FOR GAS OR VAPOR ELECTRIC APPARATUS.

SPECIFICATION forming part of Letters Patent No. 749,793, dated January 19, 1904.

Application filed May 16, 1902. Serial No. 107,803. (No model.)

To all whom it may concern:

Be it known that I, PETER COOPER HEWITT, a citizen of the United States, and a resident of New York, in the county of New York and State of New York, have invented certain new and useful Improvements in Regulators for Gas or Vapor Electric Apparatus, of which the following is a specification.

The appearance of what I have called the "negative" flame in certain types of gas or vapor electric lamps has been referred to in an application for Letters Patent of the United States, Serial No. 99,333, filed by me on the 21st day of March, 1902. In the said application reference is made to the fact that under ordinary conditions the negative flame acts as a resistance to the passage of the electric current, particularly when the flame stands in the direct line of the current between the positive and negative electrodes of the lamp. The application referred to describes mechanical means for removing the negative flame from the direct path of the current, and thereby lessening the total lamp resistance. In the same application attention is called to the fact that when the negative flame is acted upon by a magnet or solenoid the condition of lowest lamp resistance is attained when the flame lies in the direct path of the current through the lamp. It is found, in other words, that either a permanent or an electro magnet will so influence the negative flame as to change its character as a resisting medium and cause it to actually lessen the normal lamp resistance. In this connection it is to be noted that the tendency of the flame is to project itself or lie along the lines of magnetic force, and in this way the flame is made very steady by the action of a magnet, so that the normal resistance of a lamp in which the negative flame is mechanically controlled can be governed without any essential fluctuation. Accordingly if it be desired to construct a lamp with as low a normal resistance as possible, assuming a vertical type of lamp in which the negative electrode is at the bottom of the transparent container, the proper position for the magnet or solenoid would be directly below the negative electrode, with the lines of force projecting toward the lamp-electrode. This would cause a projection of the flame in an upward direction, thus bringing it into a right line with the current between the electrodes, thereby minimizing the normal lamp resistance. On the other hand, it may sometimes be desired to operate lamps at a resistance higher than the lowest possible resistance, in which case the magnet or solenoid may be located in such relation to the negative electrode as to throw the flame into other than a vertical position, thus predetermining the lamp resistance at a desired value within certain limits.

When a magnetic field is utilized for fixing the position of the negative flame or for deflecting it from the direct line between the electrodes, a permanent magnet may be employed, if desired, or an electromagnet supplied from any suitable source. By using an electromagnet, however, and putting it in series with the lamp and then so placing it with respect to the negative electrode as to deflect the flame away from the direct line it is possible to secure excellent regulation of the lamp resistance in a manner which will be described in the specification which follows. It should be said that the length of the flame and under certain conditions the amount of the deflection depend upon the strength of the magnet employed. When, for example, a vertical magnet is placed so that its poles are located anywhere below the negative electrode in a vertical lamp, successive increases of magnetic strength will project the flame farther and farther, but in a fixed direction, while if the magnetic pull be located above the surface of the negative electrode successive increases of magnetic strength will project the flame farther and farther away from the vertical, thereby increasing the lamp resistance. By these means variations in the circuit of the electromagnet, if an independent circuit, may be recreated in the circuit of the lamp with varying intensity, depending on the magnetic circuit and on the lamp-circuit.

My invention is illustrated in the accompanying drawings, in which—

Figure 1 is an elevation of one of my vertical lamps in which the flame is projected vertically upward by an electromagnet underneath the lamp. Fig. 2 is a similar view of a vertical lamp in which the flame is projected at an angle, and Fig. 3 is a diagram illustrating electromagnetic means for automatically regulating the resistance of a lamp.

In Fig. 1 the main lamp-tube is shown at 1, the respective positive and negative electrodes at 2 and 5, the same being severally connected with leading-in wires 7 and 8. Below the negative electrode 5 is arranged an electromagnet 10, energized by a suitable source 11. Under the conditions illustrated in this figure the negative flame 12 is projected vertically upward, thus giving to the lamp its lowest resistance.

In Fig. 2 the relations are changed only to the extent that the magnet 10 is shifted a little to one side, thereby causing the flame to be projected at an angle to the vertical, under which conditions the lamp has an increased resistance as compared with the lamp shown in Fig. 1.

In Fig. 3 the magnet 10 is arranged at the side of the lamp and somewhat above the surface of the negative electrode 5. Here the flame 12 is deflected, as shown, the deflection being still more marked in case the strength of the magnet 10 increases. The magnet is here arranged in series with the lamp, so that any change of potential on the line will be felt not only in the lamp but also in the magnet 10. For example, should the conditions of the circuit be so altered as to cause too great a flow of current the strength of the magnet 10 will be increased, the flame 12 will be deflected, so as to increase the lamp resistance, in consequence of which the excessive flow of current is checked. Thus the arrangement illustrated in Fig. 3 is adapted to cause a very sensitive regulation of the lamp-circuit. When the electromagnet is in an independent circuit, variations in the magnet-circuit will be reproduced in the lamp-circuit, and this arrangement may be used for many purposes—for instance, as a relay.

Means for starting the flow of current through the apparatus are set forth in certain patents issued to me on the 17th day of September, 1901.

The results described above are more readily accomplished when the flame is proceeding from a projecting point, as shown at 13 in Fig. 1, or is fixed by a plate floating on the mercury, the plate having a hole in its center, as illustrated at 14 in Fig. 2.

It is manifest that the operation of the device forming the subject of the present invention is the same whether the apparatus is used as a lamp or a source of light or for any other purpose.

I claim as my invention—

1. In an electric vapor apparatus in which a path is provided for the electric current between a positive and a negative electrode, and in whose normal operation a negative flame is developed at the negative electrode, magnetic means for projecting the flame in such a direction with relation to the path of the current between the electrodes as to produce a definite normal resistance in the apparatus.

2. In an electric circuit, an electric vapor apparatus and an electromagnet in series therewith, the magnet being placed at the side of the apparatus and in operative proximity thereto.

3. The combination with an electric circuit containing a gas or vapor apparatus, of an electromagnet, placed in such relation to the negative electrode of the apparatus that electrical variations in the magnet-circuit will be reproduced in the circuit of the apparatus.

Signed at New York, in the county of New York and State of New York, this 9th day of May, A. D. 1902.

PETER COOPER HEWITT.

Witnesses:
WM. H. CAPEL,
GEORGE H. STOCKBRIDGE.

PLAINTIFF'S EXHIBIT No. 207.

No. 758,650. PATENTED MAY 3, 1904.

P. C. HEWITT.

ELECTRODE FOR VAPOR ELECTRIC APPARATUS.

APPLICATION FILED JAN. 18, 1904.

NO MODEL.

Witnesses
Chas. F. Clapp
W. H. Capel

Inventor
Peter Cooper Hewitt.
By his Attorney
Chandler & Thorp

No. 756,650. Patented May 3, 1904.

UNITED STATES PATENT OFFICE.

PETER COOPER HEWITT, OF NEW YORK, N. Y., ASSIGNOR TO COOPER HEWITT ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

ELECTRODE FOR VAPOR ELECTRIC APPARATUS.

SPECIFICATION forming part of Letters Patent No. 756,650, dated May 3, 1904.

Application filed January 13, 1904. Serial No. 188,838. (No model.)

To all whom it may concern:

Be it known that I, PETER COOPER HEWITT, a citizen of the United States, and a resident of New York, county of New York, State of New York, have invented certain new and useful Improvements in Electrodes for Vapor Electric Apparatus, of which the following is a specification.

In the operation of a vapor electric device where the "negative electrode resistance" is comparatively small this resistance is apt to be irregular. The current enters the negative electrode at a spot and has the tendency to be constantly wandering over its surface, being visible as a bright wandering spot or flame. I have found that this may be overcome under the same conditions and that the resistance may be made stable. I have also discovered that physical or chemical disintegration takes place at the point where the current enters the negative electrode and that by constructing the electrode so that physical or chemical change will take place at a predetermined spot more easily than another the current can be made to enter this spot and cease wandering over the surface of the negative electrode. In the case where the negative electrode consists of a volatilizable material this may be done by extending from it a point of metal or other material. This point when it becomes heated by the current will cause vaporization of the material forming the electrode on or at its surface of contact and consequent fixing of the entering of the current at that place. If this point be of such a material as becomes wetted by the material of the negative electrode, it then will act somewhat in the same manner as a wick and its operation appears certain and stable. The disintegration of the negative electrode at a particular spot may be brought about by chemical means and also by the physical character and shape of the electrode.

In the accompanying drawing I have shown one form of vapor device illustrating the invention.

Referring to the drawing, 1 represents an inclosing chamber, in the present instance in the form of a tube having an enlargement 2 at one end. This enlargement serves as a condensing and cooling chamber for the vapor of the negative electrode, which for convenience in this instance will be referred to as "mercury." The negative electrode is here shown as located at the end of the tube remote from the condensing-chamber 2, which has the negative electrode 3. The positive electrode 4 is represented within the condensing-chamber. Suitable leading-in conductors 5 and 6 are connected with the respective electrodes 3 and 4. The leading-in conductor 5 is here shown as being provided with an extension of platinum, as 7, projecting slightly above the surface of the negative electrode. This extension may be comparatively thin and, in fact, may be virtually a wire. When mercury is used as the negative electrode, platinum serves excellently as the material from which to form the point 7.

The particular device here shown is represented in the form especially suited for electric illuminating purposes; but the same principle applies when the device is used for transformers or other purposes.

I claim as my invention—

1. In an electric vapor device of the character described, a fluid electrode, and a point of solid conducting material projecting above the surface thereof.

2. In an apparatus of the class described, an electrode of mercury having a solid conducting material projecting above the surface thereof.

3. In an apparatus of the class described, an electrode of mercury having a body of platinum projecting above the surface thereof.

4. In a gas or vapor electric device having a liquid negative electrode, steadying means at the negative electrode comprising a solid wetted material in contact therewith, the general surface of the solid being in a different plane from the general surface of the liquid.

Signed at New York, in the county of New York and State of New York, this 6th day of January, A. D. 1904.

PETER COOPER HEWITT.

Witnesses:
WM. H. CAPEL,
GEORGE H. STOCKBRIDGE.

252

PLAINTIFF'S EXHIBIT No. 208.

P. C. HEWITT.

MEANS FOR SUPPRESSING THE RESISTANCE OF THE NEGATIVE ELECTRODE FLAME IN ELECTRIC VAPOR APPARATUS.

APPLICATION FILED MAR. 21, 1903.

954,434. Patented Apr. 12, 1910.

Fig. 1.

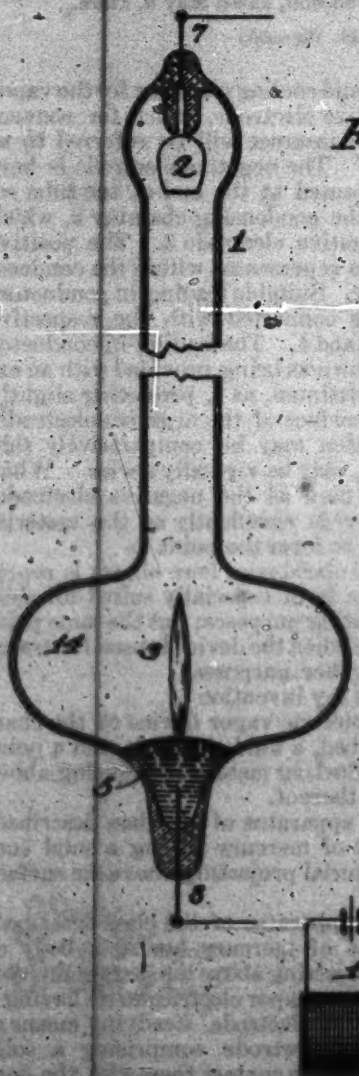


Fig. 3.

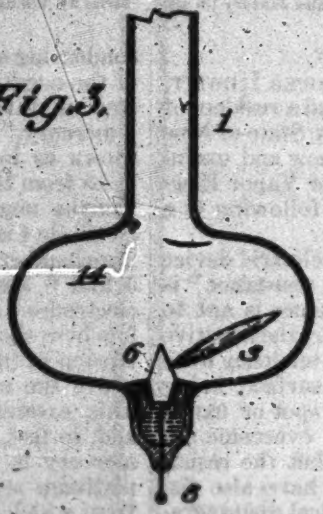


Fig. 2.

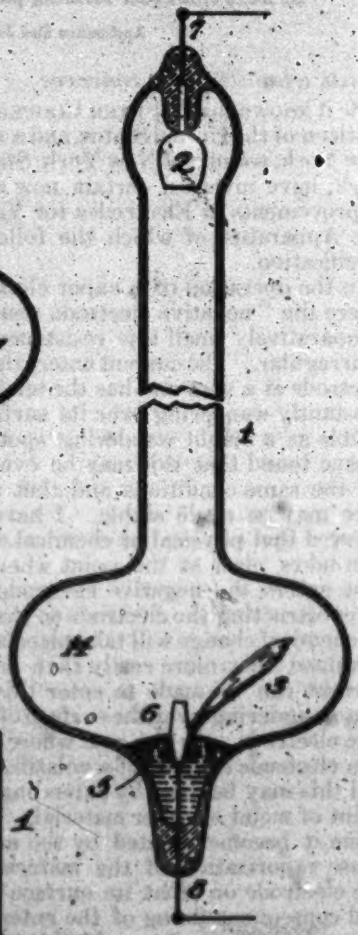
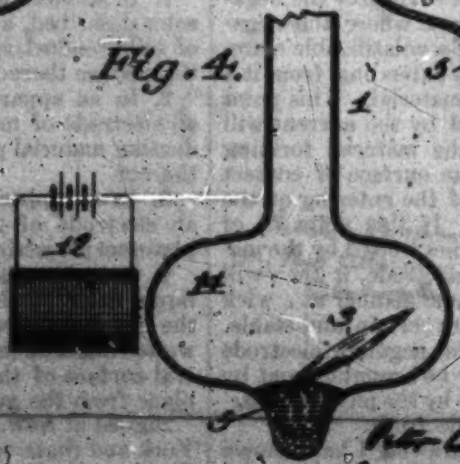


Fig. 4.



Witnesses:
Thos. D. Browne
Henry T. Miller

Inventor
Peter Cooper Hewitt
by Chester & Kenyon
Attys.

UNITED STATES PATENT OFFICE.

PETER COOPER HEWITT, OF NEW YORK, N. Y., ASSIGNOR, BY MESNE ASSIGNMENTS, TO COOPER HEWITT ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

MEANS FOR SUPPRESSING THE RESISTANCE OF THE NEGATIVE-ELECTRODE FLAME IN ELECTRIC VAPOR APPARATUS.

954,434. Specification of Letters Patent. Patented Apr. 12, 1910.

Application filed March 21, 1902. Serial No. 99,133.

To all whom it may concern:

Be it known that I, PETER COOPER HEWITT, a citizen of the United States, and a resident of New York, in the county of New York and State of New York, have invented certain new and useful Improvements in Means for Suppressing the Resistance of the Negative-Electrode Flame in Electric Vapor Apparatus, of which the following is a specification.

This invention relates to improvements in the class of vapor apparatus described and shown in various patents issued to me on the 17th day of September and the 3rd day of December, 1901.

The operation of electric vapor lamps, such for instance, as that type of the Cooper-Hewitt lamp in which mercury is used as the negative electrode, is generally accompanied by the appearance at the negative electrode of a flame which, while being somewhat unstable when the surface of the negative electrode is irregular or subject to alteration, proceeds from the negative electrode in a direction at right angles to the surface at which the current enters the said electrode. By a proper selection of the plane of the negative electrode surface, the direction which this negative flame shall take, can, accordingly, be predetermined. The investigation of the resistance of a vapor lamp, such as described, shows that when this negative flame takes the direction of the path of the current between the positive and negative electrodes of the lamp, the total resistance of the lamp is considerably greater than when the negative flame puts off at an angle to the current path. The excess in resistance under the conditions first named, may equal or exceed fifteen per cent. of the total resistance. It will be understood that the negative flame referred to is practically useless as a source of light, for which reason the electro-motive-force required to overcome the resistance occasioned by this flame serves no useful function in the lamp and is not only practically wasted but is detrimental. In order to insure that the energy applied to a lamp of this class shall be utilized in the light-giving portion thereof, without needless waste, I provide means whereby the surface of the negative electrode shall be so arranged as to insure the projection of the negative flame outside the path of current through the lamp.

The present invention relates to means for accomplishing that end.

It is also found that the direction of the negative flame is changed by the action of a magnet or solenoid, the flame tending to lie in and along the lines of force. Where it is desired that the negative flame should be out of a right line to the main path of the current, a magnet or a solenoid may furnish a convenient means for accomplishing this result but the deflection of the flame in this way by a magnet or solenoid has the effect of increasing the resistance of the lamp instead of decreasing it. In general it may be said that a wide deflection of the negative flame is desirable when produced by mechanical means, and a condition of no deflection is desirable when produced by magnetic means. The effect of the magnetic action is to maintain the flame in a stable condition.

The provisions referred to in the foregoing paragraphs are based upon the fact that the negative flame proceeds substantially at right angles to the entrance plane of the current. This means that the entrance surface of the negative electrode should be out of a plane at right angles to the path of the current, in order to cause a suitable position of the negative flame.

I have illustrated my invention in the accompanying drawings, in which—

Figure 1 is a longitudinal section of a mercury vapor lamp showing the negative flame in line with the path of current between the electrodes; Fig. 2 is a similar view of a lamp so constructed as to cause the negative flame to put off at an angle to the current path; Fig. 3 is a section of the lower part of one of my lamps, illustrating a particular form of negative electrode; and Fig. 4 is a longitudinal section of a lamp similar to that shown in Fig. 1, combined with a deflecting electro-magnet.

In the drawings, 1 is a tube or container of glass and 2 and 5 are, respectively, the positive and negative electrodes of my lamp. The electrodes are connected through the walls of the lamp to the respective lead-wires, 7 and 8. In Figs. 1, 2 and 3, the positive electrode is of iron and the negative elec-

trode is of mercury, or mercury in combination with a projecting piece of metal, generally iron. In Fig. 1, the negative electrode is of pure mercury. The negative flame is shown at, 3, projecting at right angles from the upper surface of the mercury in the direction of the path of the current between the electrode 2 and the electrode 5. In practice, it is found that the surface of the mercury electrode is subject to more or less distortion at the point where the current enters the electrode, for which reason the surface at that point may not be in a plane at right angles to the main path of the current, so that the negative flame, when the negative electrode consists entirely of mercury, may not always take the direction indicated in Fig. 1. But inasmuch as the negative flame may take the direction indicated in Fig. 1, it is desirable that this should be guarded against, by providing an entering surface for the current which shall always lie in a direction other than a right angle from the path of the current. I have found that, while the current appears to enter the negative electrode at a small point on its surface, yet it prefers to enter at a point upon a plane surface rather than at an edge or actual mechanical point or summit. A suitable formation of the negative electrode is illustrated in Fig. 2 wherein a piece of iron, 6, projects up through the mercury 5 and has perpendicular surfaces at which the current enters. With this construction the negative flame is thrown off nearly or quite at right angles to the path of the current between the electrodes.

Fig. 3 illustrates a modification of the negative electrode, in which a piece, 6, of iron, projects above the mercury and is provided with a conical or pyramidal shape, the current entering the iron at an angle other than a right angle to the main path of the current, thus causing a deflection of the negative flame.

As a simple mode of illustrating the deflection of the flame by means of magnetic force, I have shown in Fig. 4, a magnet, 12, outside the enlargement in which the negative electrode surface lies. The effect of the magnet is to deflect or turn the negative flame approximately as indicated in the drawing. The magnet may be a permanent magnet or an electro-magnet supplied from a separate source or in a series or shunt relation to the lamp. In another application, Serial Number 107,603, filed May 16, 1902, and issued as a patent on January 19, 1904, Number 749,793, I have shown and described this feature in greater detail and have claimed it as a regulating device. Also in a divisional application Serial Number 123,873, filed September 18, 1902, claims are made upon the horizontal lamp described herein.

It is manifest that this invention would apply equally well to a gas or vapor electric lamp and to a gas or vapor electric apparatus designed for any other use.

In another application Serial Number 548,071, filed March 11, 1910, which is a division of this application, I have made claims involving certain features shown and described herein.

I claim as my invention:

1. In a vapor electric apparatus, a container of suitable shape and dimensions, a positive and a negative electrode therein, and means for causing the surface of the negative electrode at which the current enters it to lie in a plane at an oblique angle to the path of the current between the two electrodes whereby the flame is caused to project itself out of the path of the current.

2. In a vapor electric apparatus, a suitable container, a positive and a negative electrode within the same, an enlargement surrounding the exposed surface of the negative electrode, and means for so shaping the surface of the negative electrode as to cause it to present an entering plane for the current traversing the lamp, which plane lies at an oblique angle to the direct path of the current between the electrodes.

3. In a gas or vapor apparatus of the character described, a container, a positive electrode, a liquid negative electrode, and a solid electrode extension projecting above the surface of the negative electrode, the surface of the projection forming an oblique angle with reference to the surface of the liquid negative electrode.

Signed at New York in the county of New York and State of New York this nineteenth day of March A. D. 1902.

PETER COOPER HEWITT.

Witnesses:
WM. H. CAPEL,
GEORGE H. STOCKBRIDGE.

PLAINTIFF'S EXHIBIT No. 209.

P. C. HEWITT.

MEANS FOR REPRODUCING ELECTRICAL VARIATIONS.

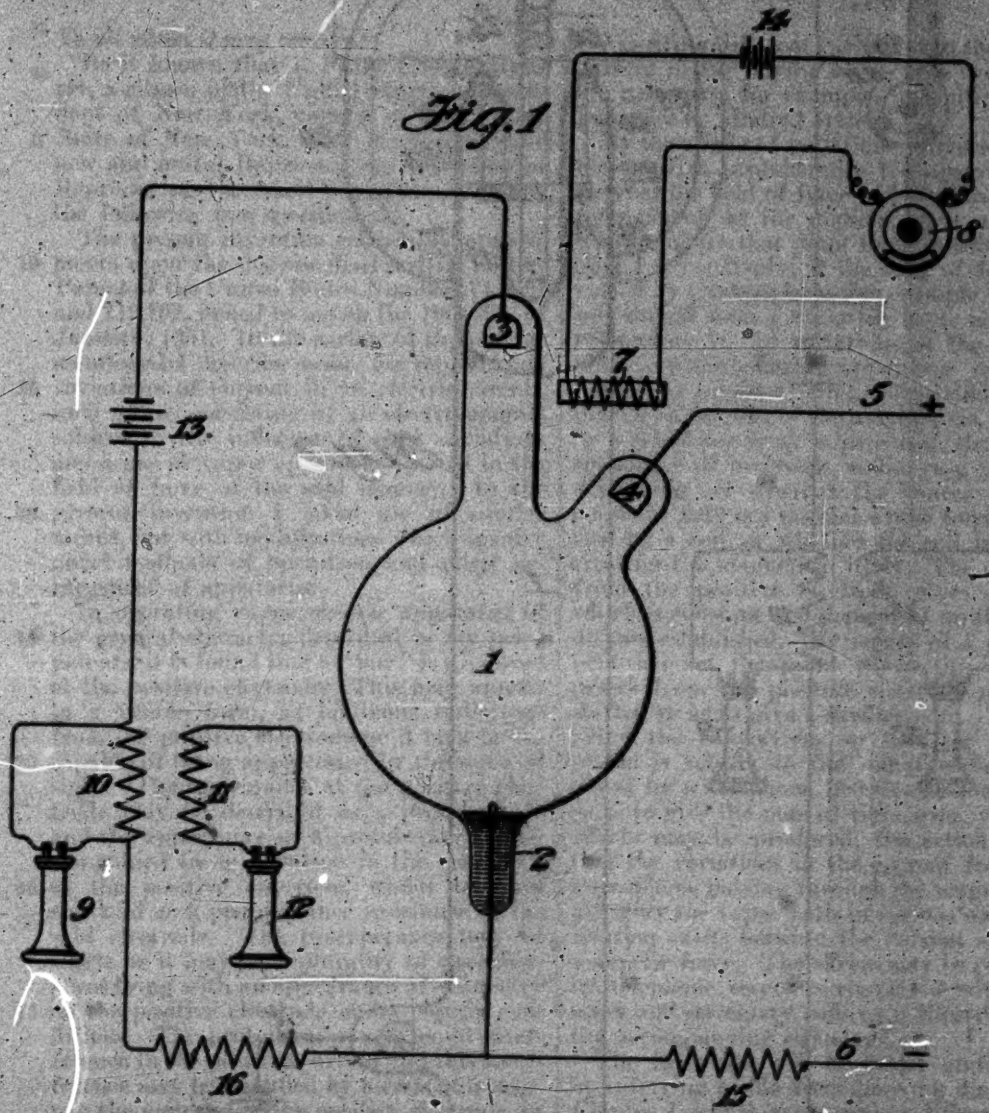
APPLICATION FILED JULY 7, 1904.

991,304.

Patented May 2, 1911.

2 SHEETS—SHEET 1.

Fig. 1



Witnesses
Chas. F. Clagett
W. F. Capel

Inventor
Peter Cooper Hewitt
By his Attorney
Charles A. Terry.

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P. C. HEWITT.

MEANS FOR REPRODUCING ELECTRICAL VARIATIONS.

APPLICATION FILED JULY 7, 1904.

991,304. Patented May 2, 1911.

2 SHEETS—SHEET 2.

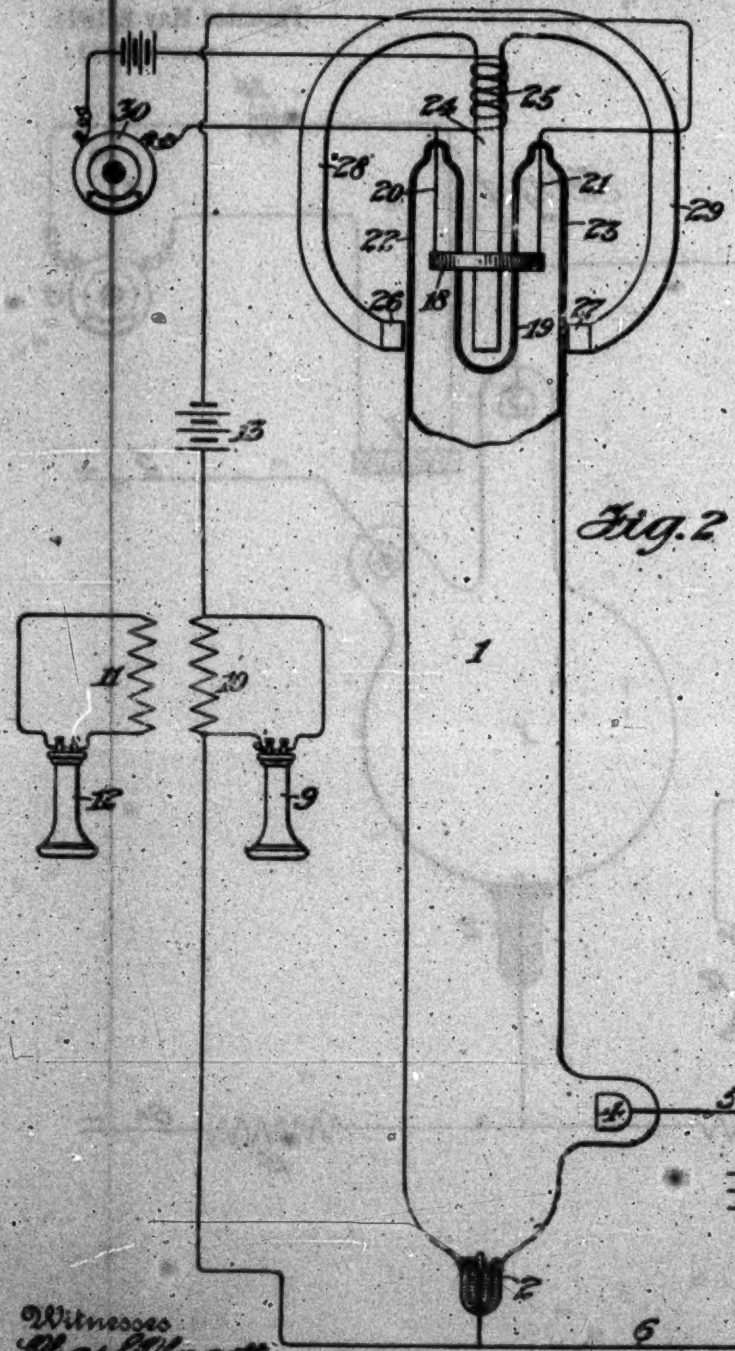

Fig. 2.

Witnesses
Chas. F. Wingett
W. L. Cabell

Inventor
Peter Cooper Hewitt
By his Attorney
Alexander A. Terry.

UNITED STATES PATENT OFFICE.

PETER COOPER HEWITT, OF NEW YORK, N. Y., ASSIGNOR TO COOPER HEWITT ELECTRIC COMPANY, OF NEW YORK, N. Y., A CORPORATION OF NEW YORK.

MEANS FOR REPRODUCING ELECTRICAL VARIATIONS.

991,304. Specification of Letters Patent. Patented May 2, 1911.

Application filed July 7, 1904. Serial No. 215,577.

To all whom it may concern:

Be it known that I, PETER COOPER HEWITT, a citizen of the United States, and resident of New York, county of New York, State of New York, have invented certain new and useful Improvements in Means for Reproducing Electrical Variations, of which the following is a specification.

The present invention relates to improvements upon the devices disclosed in Letters Patent of the United States Numbers 749,791 and 749,792, issued to me on the 19th day of January, 1904. In the earlier of the patents mentioned I describe means for reproducing variations of current in an electric circuit, such means consisting of an electro-magnet subject to the influence of said variations and a gas or vapor apparatus located in the field of force of the said magnet. In the present invention I make use of similar means, but with modifications which involve novel methods of operation and novel arrangement of apparatus.

In operating vapor electric apparatus of the general character described in my prior patents, it is found that a "bur" is produced at the positive electrode. This may appear in a visible form, as luminous radiations from the positive electrode or it may be incapable of being appreciated by the sense of sight. The appearance at the positive electrode may be described as a protuberance and the appearance of a protuberance is accompanied by a variation in the resistance at the positive electrode, which we may speak of as a protuberance resistance at the said electrode. The protuberance may be single or it may be a plurality of protuberances lying with an appearance of symmetry on the positive electrode under certain conditions. The protuberance acts as an interference to the positive current and this interference may be modified by means of a magnet, the material of the positive electrode, or by means of a particular construction of the surroundings of the positive electrode, so as to create variations of period in the current through the apparatus. By a proper proportioning of the various forces at work, the variations may be made very long, or may be superimposed on each other, or they may be variations so rapid as to be inaudible. The arrangement as a whole may be utilized for creating different variations in the direct current in any circuit where such variations are necessary, for example, in multiplex telegraphy or kindred systems.

By the effects of variations produced upon the positive protuberance the operation of varying the field of force will produce a note commencing at the audible point, and extending above that point to an indefinite region. Accordingly, if the field of force be varied by a microphone for example, the result should show a variation in its note corresponding to the variations of the microphone, whereby the apparatus may be caused to produce notes corresponding or inverse to the note of the microphone, whereby a telephone relay is provided, the correspondence or inversion, as the case may be, depending on whether the source of the magnetic field is a magnet whose force is varied by a coil, or whether the coil is a coil creating the magnetism itself. The current from the positive electrode gives a note which is constant and dependent on the conditions established. By means of a permanent magnet the point where the current passes from the positive electrode may be shifted so as to give a shriller note. By varying the connections so that the microphone is subject to the sound waves produced by a telephone instrument connected so as to give the note of the source, varying effects may be produced, the action being that the variations in the current from the microphone passing through the magnet coil influence the vapor path in various ways. A relation exists between the current and the magnetic force. The effects may be received by telephone receivers connected with primary and secondary coils as is illustrated in the accompanying drawings.

The invention will be better understood by referring to the accompanying diagrams, Figures 1 and 2, representing different embodiments of my invention.

Referring to the first figure of the drawing, 1 is a hermetically sealed vessel of glass or other suitable material containing a negative electrode 2, and positive electrodes, 3 and 4. The latter may be of some suitable material, such as iron, and the negative electrode may be of mercury or other conductor and preferably capable of low electrical re-

sistance and having a point or equivalent projection from the surface. The electrode 4 is a supplemental electrode, the main electrodes being 2 and 3. The apparatus having been started, the negative electrode resistance may be maintained in a condition of being broken down by means of current flowing between the electrodes 4 and 2 and supplied through mains 5 and 6, connected with a source furnishing a supply of current in one direction. I may now place so as to influence the container 1, a magnet, 7, connected in circuit with a telephonic transmitter, 8, or other source of variation. In circuit with the main electrodes I may place a telephone receiver, or other receiver, 9, in shunt to a reactance coil, 10, which may be the primary of a transformer, the secondary of which is shown at 11 as being connected in a circuit with a second telephonic receiver, 12, in which case the first may be omitted, if desired. If, now, the transmitter 8 be affected by vibrations, say through the human voice, the variations of magnetic effect in the circuit including the magnet 7 will be reproduced in the vapor device 1 and consequently in the circuit connected with the main electrodes 3 and 2 of the said vapor device. Effects of the variations caused by the changes in the field of force of the magnet 7 being thus reproduced can be observed in the receiver 9 or the receiver 12, as the case may be. Inasmuch as a slight variation in the field of force of the magnet 7 may cause a considerable variation in the resistance of the vapor device, which last named variation will be reproduced in the receiving circuit, the apparatus as a whole may serve as a relay adapted to magnify the effects originally produced at the transmitter 8. In the circuit between the main electrodes 3 and 2 I include any suitable source of current, such, for example, as the battery, 13, indicated on the drawing, and further these effects may be amplified by including in the circuit a vapor device such as my lamps, care being taken to keep the negative electrode resistance in a state of good conductivity in which the resistance varies substantially inversely with the current, which forms a suitable proportion of the resistance of its circuit for augmenting the variations. The transmitter circuit also contains the usual battery, 14. In the circuit of the direct current source I may insert the resistance, as 15, and I may also insert the resistance, 16, in the circuit between the main electrodes. When placed in a similar manner as shown and described in Fig. 1 the magnet 7 will directly influence what I have called the protuberance resistance at the positive electrode. By thus influencing this resistance, the interference of the protuberance with the positive current is modified and thus variations of period in the current through the apparatus are produced. It will be understood that a different location of the magnet 7, as by placing it lower down along the container would still produce variations in the resistance of the apparatus, which variations would be reproduced in the external circuit. The effects produced by such a relation of the parts has already been made the subject of patents issued to me; namely, 749,791 and 749,792.

In Fig. 2 I show a different embodiment of my invention, the parts 2 and 4 and the circuit 5 serving substantially the same function as before. In the circuit described I show in this instance a direct current source, 17, serving to keep the apparatus alive. The main positive electrode in this embodiment of the invention appears at 18 as a ring of conducting material surrounding a reëntrant portion 19 of the tube or container 1. The ring 18 is supported upon lead-wires, 20 and 21, leading into the apparatus through tubular extensions, 22 and 23, respectively. Into the reëntrant portion of the device I insert the core, 24, of a magnet, 25, the core may be provided with pole-pieces, 26 and 27, formed, respectively on arms, 28 and 29, which are in one piece with the core, 24, instead of a plain straight core. The pole pieces are so arranged as to lie outside the tube or container 1 in proximity to the positive electrode 18. The coils of the magnet 25 are connected with the terminals of a microphone or telephonic transmitter, 30. As before, the positive electrode is connected with a battery or other source 13 with one side of a reactance device 10, the other side of which is connected with the negative electrode 2. The reactance device 10 is, in this instance as before, the primary of a transformer and in shunt to the said primary is a telephonic receiver 9 while the secondary 11 of the said transformer is connected with a telephonic receiver 12. From what has been said respecting the action of the apparatus illustrated in Fig. 1, the action of this apparatus will be clearly understood.

I claim as my invention:—

1. As a means for reproducing the variations of current in an electric circuit, an electromagnet subject to the influence of said variations, and a gas or vapor apparatus of the character described located in the field of force of the said magnet, the magnet being placed in such relation to the positive electrode as to cause the variation of the protuberance resistance to be large relative to any variation produced by the said magnet in the vapor column resistance.

2. As a means for reproducing the variations of current in an electric circuit, an electro-magnet subject to the influence of said variations, and a gas or vapor apparatus, of the character described located in the field of force of the said magnet, the

magnet being placed in proximity to the positive electrode, a main circuit through the gas or vapor apparatus, and supplemental means for keeping the said apparatus alive.

3. As a means for reproducing current variations in an electric circuit, an electromagnet subject to the influence of said variations, a gas or vapor apparatus located in the field of force of the said magnet, means for passing electric current through said apparatus, and a receiving apparatus subject to the influence of variations of resistance in the circuit of the gas or vapor apparatus, in combination with supplemental means for maintaining the gas or vapor apparatus alive.

4. The combination with a vapor device including a hermetically sealed and completely exhausted container and an anode, and vaporizable reconstructing cathode therein, the said anode and the protuberance therefrom being located in a relatively narrow extension of the main body of said container, of a magnet adapted to receive and transmit variations of energy placed adjacent to said protuberance and varying the resistance thereof in relation to the variation of its received energy.

5. The combination with a telephonic transmitting circuit, a telephone receiver, a circuit including the latter, a gas or vapor path, means for passing electric current therethrough, said path being so related to the latter as to affect the same by variations of resistance in the circuit of the gas or vapor apparatus, and an electro-magnet traversed by electric currents due to effects in the transmitting circuit, and acting upon the gas or vapor path, and supplemental means for maintaining the gas or vapor electric apparatus alive.

6. The combination with a vapor device including a hermetically sealed and completely exhausted container, an anode, a vaporizable reconstructing cathode and a surface extending upward from the main surface of said cathode therein, of a magnet adapted to receive said transmit variations of energy located adjacent to said protuberance and producing therein a change of resistance corresponding to variations in its received energy, said resistance changes being relatively great as compared to any variations in the resistance of the vapor column.

7. The combination with a hermetically sealed and completely exhausted container, a plurality of anodes and a vaporizable reconstructing cathode in said container, a solid in contact with the surface of said cathode, means for passing continuous current from one of the said anodes to said cathode and means for varying the resistance of a vapor path to another of said anodes by other waves from an outside source of electrical variations, of a receiving circuit including a telephone and a source of electromotive force in circuit with said last named anode and said cathode.

8. The combination with a generator of energy variations in the other, of a vapor electric device including a cathode and an anode, a source of current therefor and a receiving circuit sensitive to rapid variations of electrical energy, said circuit including a separate anode in said vapor electric device, together with means for causing said energy variations in the other to produce variations in the vapor path to said separate anode.

9. The combination with a generator of energy variations in the other, of a vapor electric device including a cathode, an anode, and a relatively excessive condensing chamber, a suitable source of current therefor and a receiving circuit sensitive to rapid variations of electrical energy, said circuit including a separate anode in said vapor electric device, together with means for causing said electrical variations in the other to produce variations in the vapor path to said separate anode.

10. In a system of electrical distribution the combination with a hermetically sealed exhausted container and a mercury cathode therein, of anodes therein, each anode being in a tubular extension of said container together with a separate source of current connected with each anode and the said cathode.

Signed at New York, in the county of New York, and State of New York, this 30th day of June A. D. 1904.

PETER COOPER HEWITT.

Witnesses:
WM. H. CAPEL,
CHARLES H. STOCKMAYER.

PLAINTIFF'S EXHIBIT No. 210.

By the Court:

Q10. What was that repeater? A. That was a mechanical repeater.

By Mr. Neave:

Q11. Was it a Shreeve repeater? A. It is known as the Shreeve repeater.

Q12. To what extent has the Bell System put mechanical repeaters into use, or sold them to others for use in the United States; how many were in service each year from the beginning? A. Under my direction a statement has been prepared by one of my assistants which shows that. The statement is as follows:

MECHANICAL REPEATER INSTALLATIONS
1904-1918

	On Toll Circuits		Amplifiers for Loud Speaking Receivers			Service Observing Circuits.
Repeater Sets Installed as of	2-way type	1-way type	Sub-station type for deaf persons	Centralized Testing.	R.R. use etc.	
Dec. 31, 1904	2					
Dec. 31, 1905	8		1			
Dec. 31, 1906	20		3			
Dec. 31, 1907	22		3			
Dec. 31, 1908	22		3			
Dec. 31, 1909	25		5			
Dec. 31, 1910	32		7			
Dec. 31, 1911	28		6			
Dec. 31, 1912	29		9			
Dec. 31, 1913	32		11			
Dec. 31, 1914	81	12	11		2	1
Dec. 31, 1915	89	12	12		6	2
Dec. 31, 1916	90	10	12	18	62	3
Dec. 31, 1917	86	10	12	13	82	3
Dec. 31, 1918	70		15	58	90	3

PLAINTIFF'S EXHIBIT No. 210-A.

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Bancroft Gherardi—For Defendant—Direct.

fiers". I have been meaning the same thing by the words; have you? A. I have been, in this case, yes.

Q. You have produced in tabulated form a statement showing the number of mechanical repeaters in use each year since you began to use them. Can you give a similar tabulated statement showing the use each year of the audion and the mercury type repeaters by the Bell System, and with that same tabulated statement I would like to have a resume of the use of mechanical repeaters that you have already given in another form. A. I have had such a statement prepared. It is as follows:

REPEATER INSTALLATIONS

1904-1918

Repeater Sets Installed as of	Mechanical 2-way type	Mechanical 1-way type	Audion 2-way type	Audion 1-way type	Mercury Arc 2-way type	Mercury Arc 1-way type
Dec. 31, 1904	2					
Dec. 31, 1905	8	1				
Dec. 31, 1906	20	3				
Dec. 31, 1907	22	3				
Dec. 31, 1908	22	3				
Dec. 31, 1909	25	5				
Dec. 31, 1910	32	7				
Dec. 31, 1911	28	6				
Dec. 31, 1912	29	6				
Dec. 31, 1913	32	11	2			
Dec. 31, 1914	81	26	11	12	1	
Dec. 31, 1915	89	32	43	15		12
Dec. 31, 1916	90	100	150	12		10
Dec. 31, 1917	86	120	463	12		10
Dec. 31, 1918	70	166	973			

PLAINTIFF'S EXHIBIT No. 211.
Pring & Parker Article, Philosophical Magazine, 1912, Vol. 23, pp. 192-200.

IONIZATION PRODUCED BY CARBON AT HIGH TEMPERATURES

XVI. *The Ionization produced by Carbon at High Temperatures.* *By* J. N. PRING, *D.Sc., and* A. PARKER, *University of Manchester.**

The escape of negative electricity from heated carbon was noticed by Edison † when making experiments with lamp filaments. This leak of current from a heated filament to an adjacent electrode which is at a positive potential relative to the filament can, in some cases, become of the same order as that conducted through the filament. Edison found that when these filaments have been used for some time the ionization effect diminishes, but increases again if the carbon is allowed to stand.

O. W. Richardson ‡ made systematic measurements of the ionization produced by carbon. Use was made of a carbon filament and a surrounding metal cylinder, and between these a potential difference varying from 30 to 300 volts was maintained, the heated carbon being made negative. The current produced by ionization was conducted across to the surrounding metal. By exhausting to very low pressures, from 0.1 to 0.001 mm. the influence of the ionization of the surrounding gas was supposed to be eliminated, and the currents produced were considered to be due to the liberation of corpuscles from the carbon.

It had previously been stated by M'Clelland § that the negative ionization from metals is independent of the pressure over a range from 0.04 to 0.004 mm. The ionization currents found by Richardson, and attributed to the liberation of corpuscles, ranged from 10^{-8} to

* Communicated by Prof. E. Rutherford, F.R.S.
† Engineering (1884), pv 553.
‡ Phil. Trans. (1903) A. cci. p. 497.
§ Proc. Cambr. Phil. Soc. x. p. 241; xi. p. 299.

2 amps. per square cm. of carbon, according to the temperature. A formula which had been deduced to show the relation between ionization and temperature was found to be in good agreement with the experimental results. In this equation $I = A\theta^{1/2} e^{-\frac{b}{\theta}}$ where I denotes the ionization, A and b are constants, and θ is the absolute temperature. In the case of carbon, Richardson found that $A = 10^{34}$ and $b = 9.5 \times 10^4$. According to this formula, the ionization will increase at a rate which at 1500° is about equal to the 50th power of the temperature. As is well known, there are no means of precisely estimating the temperature of thin filaments.

F. Deininger † investigated the ionization from carbon and various metals alone, and in presence of lime, and concluded that Richardson's formula applied in every case up to 1450°. Thus $\log I - \frac{1}{2} \log \theta$ was plotted against $\frac{1}{\theta} 10^4$, and found to give a straight line. No mention is made of the pressure.

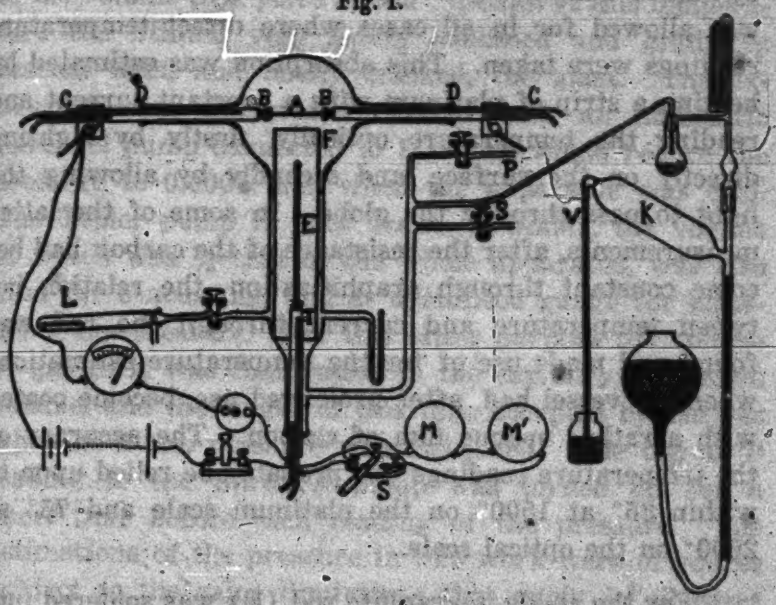
H. A. Wilson ‡ investigated the ionization from platinum and found that this varied very much with the previous treatment of the metal. Thus, by long continued heating, or else by previously submitting to the action of nitric acid, the ionization was largely diminished. He concluded that the ionization from platinum is independent of the pressure from 0.2 to 0,001 mm., but that a reduction to $\frac{1}{250,000}$ of the original ionization is produced by removing the last traces of occluded hydrogen. Wilson states that in some experiments carried out with carbon he confirmed the general results of Richardson.

The present work was undertaken with a view to examine the ionization from carbon at temperatures which were more accurately measured than in previous work, to extend these up to about 2000°, and, at the same time, to notice what influence is exerted by the pressure of the surrounding gas and the condition of the carbon. No attention seems to have been paid by previous workers to the chemical purity of the carbon.

† *Ber. deutsch. physik. Gesell.* (1907) ix. p. 674.
‡ Phil. Trans. (1904) A. ccii. p. 243.

The apparatus used in the present work (fig. 1) was

Fig. 1.



designed primarily for examining the phenomena at the anode during the discharge with high currents, and consisted of a tubular glass flask, in which a carbon rod (A) was supported by inserting in the graphite plugs B, B, which themselves were soldered into the water-cooled brass tubes C, C. An air-tight joint was made at D, D, by means of soft wax. The water-cooled tubes served for leading in the current which was used to heat the carbon. The carbon rod used was 5.1 cm. long and 0.50 mm. diameter, or 8.01 sq. cm. surface. This arrangement of the apparatus enabled the rod to be heated to 2200°.

Temperature Readings.—Accurate temperature readings were taken with a Wanner optical pyrometer. This was directly calibrated against a standardised thermocouple up to 1400°, and at the "black body" melting-point of platinum, 1545° *, and as carbon has been found

* Holborn and Henning, *Sitzungsber. k. Acad. Wiss. Berlin* (1905) xii. p. 311.

to radiate approximately as a "black body," the temperature readings will follow closely the platinum scale. The small amount of absorption through the glass vessel was allowed for in all cases where direct temperature readings were taken. This absorption was estimated by heating a strip of platinum with a constant current and reading the temperature optically, firstly by sighting directly on the surface, and secondly by allowing the light to pass through the globe. In some of the latter measurements, after the resistance of the carbon had become constant through graphitization, the relation between temperature and current through the rod was found and made use of for the temperature estimations when the vessel had, after prolonged use, become coated with a rather opaque film of carbon. The accuracy of the temperature readings can probably be relied upon to within 35° at 1500° on the platinum scale and 75° at 2000° on the optical scale..

For the anode, a graphite rod (E) was soldered into the water-cooled brass tube (T), the top being placed at 4.8 cm. distance from the carbon (A). During the experiment, a large difference of potential (usually 330 volts) was maintained between E and A; the high-potential circuit being connected through the galvanometers M and M′ which were of different ranges, one giving a deflexion of one scale-division for 4.1×10^{-9} amp. and the other of one division for 6×10^{-7} amp. For higher currents these were replaced by a milliammeter reading to 0.5 amp. and for measuring currents during discharge an ammeter reading to 30 amps. was used. By means of the two-way switch S the galvanometers were thrown out of circuit except during the moment when readings were being taken.

Exhaustion of Apparatus.—In the early experiments use was made of lithium for reducing the pressure. For this purpose the metal was placed in an iron boat contained in a tube of Jena glass (L). By surrounding this tube by an electrical furnace, and using a thermo-junc-

tion pyrometer, it was found that beginning with low pressures absorption of the gas to within one per cent. of the volume took place at 450°, though at this temperature the lithium very slowly sublimed and gradually reacted with, and finally cracked, the glass. The exhaustion was afterwards effected with an automatic Sprengel pump connected to P, which would reduce the pressure to 0.0001 mm. when the apparatus was cold. The Töpler pump K (not drawn to scale), the volume of which was ⅛ that of the whole apparatus, was also used for evacuating, and as a McLeod gauge for measuring the pressure. For this latter purpose the volume of gas in K was compressed in the capillary, of known volume, and the length of this tube occupied by the gas when at 5 cm. pressure was measured. The tap at P leading to the Sprengel pump was turned off for a short time before each reading of the pressure. The estimations of the pressure in this work were of course subject to the same limitations that apply in all cases where use is made of the McLeod gauge, through the presence of condensible gases and surface condensation on glass.

Purification of Carbon.—The carbon used consisted of amorphous retort carbon and contained about 2.5 per cent. ash (oxides of iron, silicon, &c.), and 0.2 per cent. of combined hydrogen. The method of purification employed consisted in heating for long intervals at temperatures varying from 1700° to 2000°, and maintaining very low pressures. In this way impurities are gradually volatilized away and occluded gases expelled. It has never been found possible to purify carbon completely *, on account of the tenacity with which it holds many elements in large quantities at temperatures greatly above their points of volatilization. (After use in the experiments below, the carbon was analysed by combustion in oxygen and found to contain 0.091 per cent. of ash.) The graphite rod E was occasionally heated during the above treatment by causing a discharge to pass between

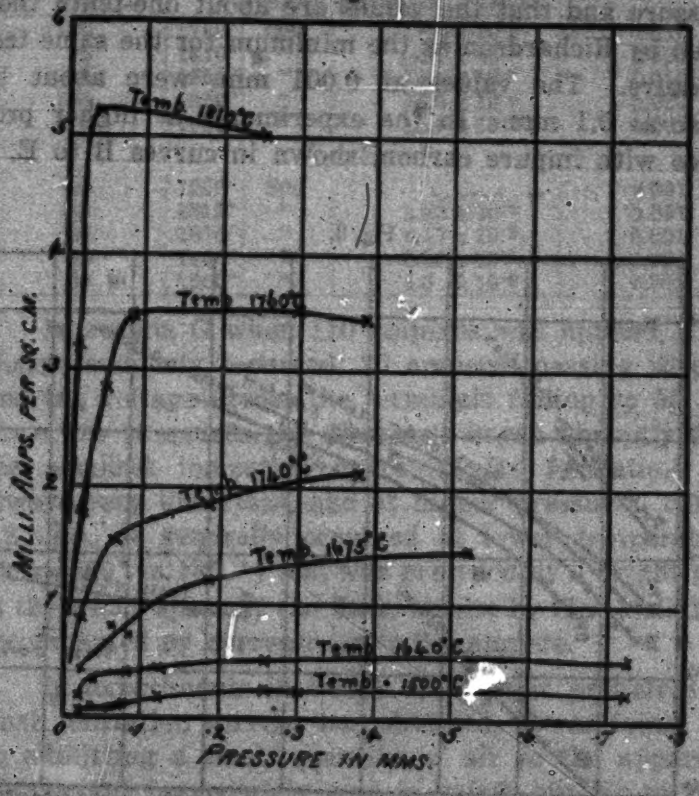
* *Cf.* Pring, Trans. Chem. Soc. (1910), xcvii. p. 504.

this and the heated carbon rod. Suitable conditions of temperature of the rod and pressure were arranged, and a potential difference of about 250 to 350 volts was applied between the carbon and the graphite. When the discharge was once started, a voltage of 40 to 60 was sufficient to maintain a current of 20 to 30 amperes, and the graphite was gradually raised to a bright white heat at the end, and the inside glass cylinder (F) to the softening point. After heating the carbon rod in this manner for some 20 to 30 hours it was found possible, at any time when the apparatus was cold, to reduce the pressure in the vessel to 0.0001 mm. within 2 hours. On raising the temperature of the rod, however, the pressure always rose immediately and amounted to about 0.01 mm. when at 1800°. This could not be reduced any further by long continued heating and exhausting. After the globe had become coated with a thin film of carbon, the pressures obtained when the rod was heated were higher than before, and for a given temperature of the rod remained constant, even after heating and pumping for several days. This residual gas is probably due either to carbon monoxide which would be formed by reaction between the oxides of the glass and the deposited film of carbon, a reaction which would proceed to a certain equilibrium value at any given temperature, or else it is due to oxygen resulting from slight dissociation of the oxides in the glass, though the temperature of the latter, of course, never reached the softening point.

Measurement of Ionization.—A potential difference of about 330 volts was applied between E and A (fig. 1) except where otherwise stated, and the latter made negative. In this way it was hoped to collect most of the ions coming from the carbon. At this voltage, however, the original ionization must have been increased by collision, as only about half the current was obtained on using 200 volts. It was found that by placing the graphite rod E at 11 cm. instead of 4.8 cm. from the carbon, a fall in the ionization current of not more than one-fifth was caused. The results obtained when using

impure carbon are shown in the form of curves in fig. 2,

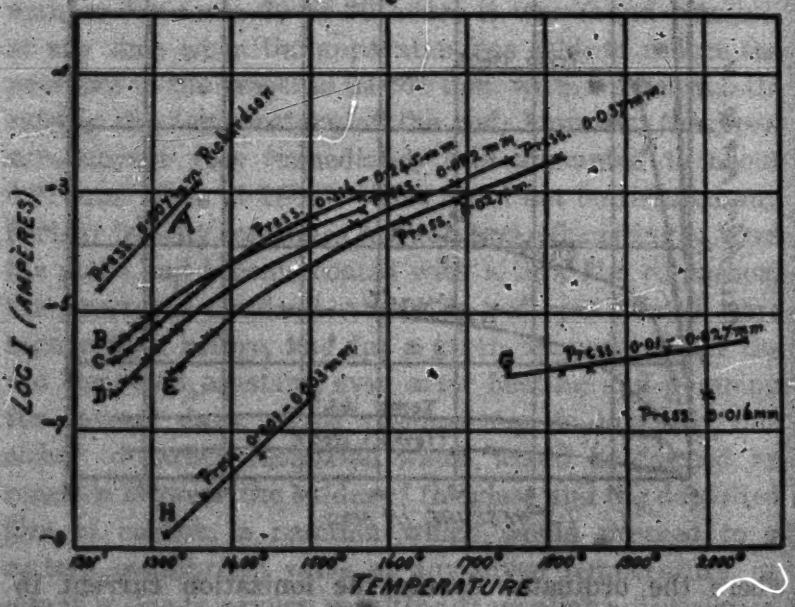
Fig. 2.



where the ordinates denote the ionization current in milliamperes per 1 sq. cm. surface of carbon and the abscissæ, the pressures. In fig. 3 are seen the results of another series of experiments which were extended to much lower pressures, and where a higher degree of purity of the carbon was obtained. In this diagram the ordinates denote the logarithm of the ionization currents (in amperes) for one square cm. of cathode surface, and the abscissæ, the temperatures. The results obtained by Richardson are shown in this diagram at A. In the present work it was found that the minimum of ionization is not obtained at the pressures used by Richardson, but that the values fall continuously with diminution of pressure and with continued use of the same carbon as it becomes progressively purer. Beginning with higher

pressures and unpurified carbon, it was found that the maximum ionization current is obtained at about 0.1 mm. pressure and that the values are about one-tenth those given by Richardson as the minimum for the same temperature. The values at 0.001 mm. were about 1/10 those at 0.1 mm. In the experiments at higher pressures with impure carbon, shown in curves B to E, at

Fig. 3.



temperatures between 1250° and 1820°, if the values of $\log I - \frac{1}{2} \log \theta$ are plotted against $\frac{1}{\theta} 10^4$, a straight line is obtained; but at higher temperatures, which were taken up to 2050°, and lower pressures, the ionization increased with the temperature far less than is required by Richardson's formula, and varied very much with the condition of the carbon. Curves B to E were carried out with impure carbon, and G and H after heating at temperatures between 1500° and 2100° and pressure between 0.005 and 0.05 mm. for a total period of about 40 hours. The values obtained in G and H, as typical experiments, are given in the table below.

Amps. through rod.	Temp.	Field (volts).	Ionization, amperes per sq. cm. cathode.	Pressure in mm.
		G.		
80	1750°	200	8.0×10^{-6}	0.010
85	1810°	"	8.6×10^{-6}	0.021
90	1850°	"	10.6×10^{-6}	0.010
100	1950°	"	16.0×10^{-6}	0.020
110	2050°	"	16.0×10^{-6}	0.027
		H.		
40	1250°	300	.....	0.001
45	1315°	"	1.23×10^{-6}	0.001
50	1370°	"	6.17×10^{-6}	0.001
55	1440°	"	3.29×10^{-7}	0.002
60	1500°	"	4.0×10^{-6}	0.003

In results G when 110 amperes was applied, a discharge suddenly occurred, 20 amperes passing through and the voltage across the terminals falling to 50. At these low pressures the discharge began abruptly from the smallest ionization current. Its formation was always very uncertain, and at higher pressures, 0.05 to 0.2 mm., it generally occurred at lower temperatures (*i. e.* 1550° to 1850°) and was preceded by a bright glow in the whole space of the flask, or else by blue striations, accompanied by currents up to 0.5 ampere.

In experiments in which at the low pressures the small ionization current was obtained, it was found that on admitting a small quantity of air to the apparatus the current immediately rose to values similar to those shown in curves B to E. There was no measurable positive ionization produced from the carbon, up to 2000°, when the field (of 200 volts) was reversed.

Summary.

Measurements were made of the ionization produced by heated carbon at definitely known temperatures between 1300° and 2050°, and at various pressures.

The negative ionization from heated carbon was found to fall continuously both with reduction of the pressure and with progressive purification of the carbon.

The lowest value found at 1300°, with a potential difference of 330 volts, was 1.5×10^{-9} ampere per square cm. surface of carbon, whereas Richardson found at this temperature 1.3×10^{-4}. At 2000° with a potential dif-

ference of 200 volts, the lowest value found was 4×10^{-7} ampere, while Richardson's formula gives, at this temperature, about 100,000 amperes.

Above 1800° the ionization only increased very slightly with the temperature.

These results clearly show that the large currents hitherto obtained with heated carbon cannot be ascribed to the emission of electrons from carbon itself, but that they are probably due to some reaction at high temperatures between the carbon or contained impurities and the surrounding gases which involves the emission of electrons.

We are deeply indebted to Prof. Rutherford and Dr. H. Geiger for much valuable advice during the course of this work.

Physical Laboratories,
Victoria University,
Manchester.

Addendum.

Effects similar to the above results obtained with carbon have been noticed by Soddy * in the case of the Wehnelt lime cathode. It was found that, at very low pressures, this cathode ceased to produce ions, whereas, according to previous experimenters, greater saturation currents were given the lower the pressure. Soddy concludes that electronic emission can only account for a negligible fraction of the total current, the remainder being carried by the residual gas.

Richardson † reaffirms the opinion that the negative leak from hot platinum is independent of the pressure at low pressures, and that these gases "only appear to increase the fundamental electronic discharge from the hot cathode by a process involving the occurrence of ionization by collisions."

Wehnelt ‡ also contradicts the above inference of Soddy, and states that in the best possible vacuum the total current is sustained by the electrons emitted from the glowing oxides, and indeed at all pressures below about 0.1 mm.

* 'Nature,' lxxv., p. 53 (1907).
† 'Nature,' lxxv., p. 197 (1907).
‡ *Phys. Zeitsch.*, ix. p. 134 (1908).

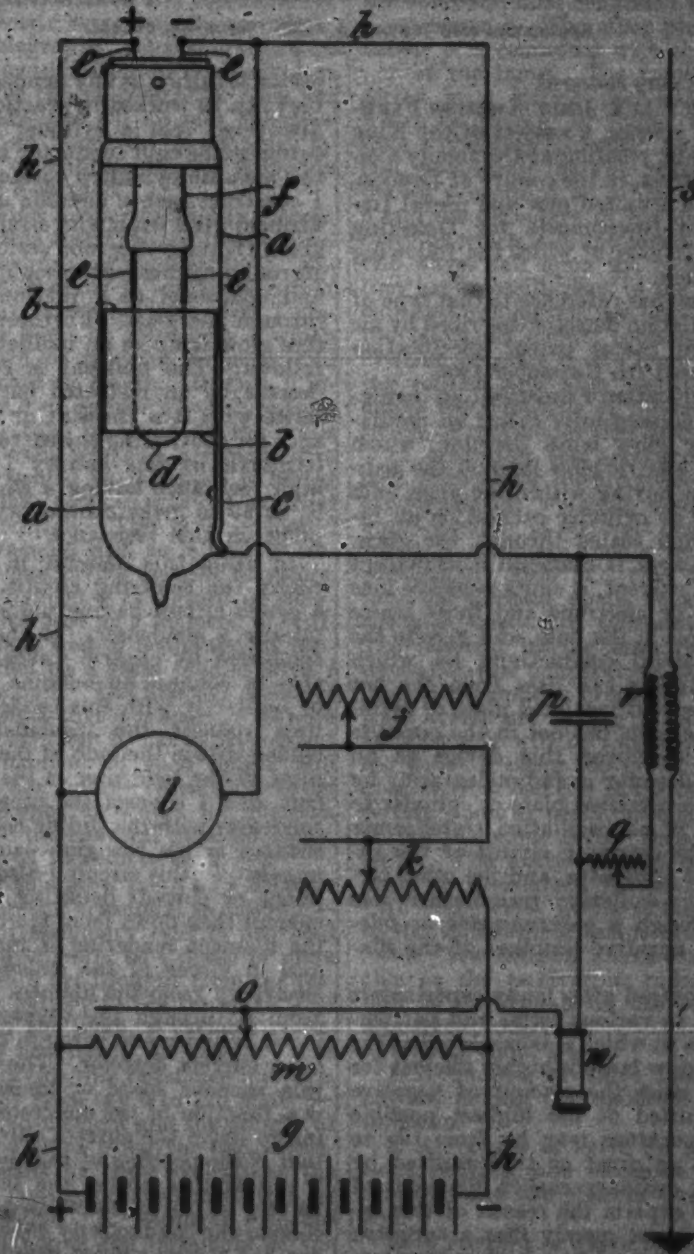
PLAINTIFF'S EXHIBIT No. 212.

J. A. FLEMING.

INSTRUMENT FOR DETECTING ELECTRIC OSCILLATIONS.

APPLICATION FILED JAN. 2, 1903.

954,619. Patented Apr. 12, 1910.



Witnesses.
Edw. W. Vaill Jr.
John [illegible]

Inventor.
John Ambrose Fleming
By his Attorneys
[illegible]

UNITED STATES PATENT OFFICE.

JOHN AMBROSE FLEMING, OF LONDON, ENGLAND, ASSIGNOR TO MARCONI WIRELESS TELEGRAPH COMPANY OF AMERICA, OF NEW YORK, N. Y., A CORPORATION OF NEW JERSEY.

INSTRUMENT FOR DETECTING ELECTRIC OSCILLATIONS.

954,619. Specification of Letters Patent. Patented Apr. 12, 1910.

Application filed January 9, 1906. Serial No. 470,484.

To all whom it may concern:

Be it known that I, JOHN AMBROSE FLEMING, doctor of science, a subject of the King of Great Britain, residing at University College, Gower Street, in the county of London, England, have invented new and useful Improvements in Instruments for Detecting Electric Oscillations, of which the following is a specification.

My invention has reference to that type of electrical oscillation detector described by me in the United States patent specification No. 803684 dated 7th November 1905.

In this specification I described an oscillation detector subsequently called an oscillation valve or glow lamp detector, which consists of an electric glow lamp of the ordinary type, but having within the glass bulb a metal plate or cylinder carried on an insulated terminal sealed through the glass. When the filament is rendered incandescent by an electric current, it emits negative ions or corpuscles or electrons and these ionize the residual gas in the bulb, and give to the space a unilateral conductivity by which negative electricity can pass from the hot filament to the cold insulated plate or cylinder within the bulb, but not in the opposite direction. I employed this device as an electric wave detector in radiotelegraphy by connecting the insulated plate or cylinder to one terminal of an oscillation transformer inserted in the receiving circuit of the radiotelegraphic apparatus, and the other terminal of this oscillation transformer was connected through a galvanometer or telephone to the negative terminal of the filament.

I have discovered after many experiments that tungsten in various forms and particularly in a form in which it is employed as the filament in a glow lamp is highly efficient for this purpose since the amount of negative electricity emitted at the highest possible working temperature may be from ten to twenty times as great as that emitted by carbon in an ordinary carbon filament. I am unable to explain the reason of this superiority; it is not merely that a tungsten filament can be raised to a higher temperature than a carbon filament, for metals such as tantalum which are closely analogous to tungsten and which can be raised to an equally high temperature are not much superior to carbon at any temperature at which they can be worked in practice. I have also discovered that a cylinder of carbon acts better as the cold conductor in the bulb than the metallic cylinders heretofore employed. I construct such a metallic or semi-metallic filament glow lamp with a tubular glass bulb and a cylinder of carbon sealed into the bulb, surrounding but not touching the filament, and connected to a platinum wire sealed through the glass. Furthermore, I employ this glow lamp as an oscillation detector as follows:—The filament is rendered incandescent by an insulated battery having in series with it a rheostat or variable resistance for controlling the current. Across the terminals of this battery I place another high resistance having a sliding contact in it, so as to make contact with any desired point on this resistance.

In using this detector in wireless telegraphy the receiving circuit must comprise a closed circuit having inductance and containing a condensor. If the telegraphy is conducted by electric waves it is necessary also to connect an antenna either directly or indirectly with this condenser circuit. I then connect the insulated cylinder included within the bulb of the lamp with one plate of the condenser in the oscillation circuit, and I connect the other plate of this condenser with the sliding contact on the resistance across the glow lamp battery terminals. In this circuit I also include a telephone or current detecting instrument. A current then flows from the battery through the filament rendering it incandescent, and also in virtue of the emission of negative electricity from the filament a current flows from it through the vacuous space to the metal cylinder and through the telephone or other current detector. The conductivity of this vacuous space or ionized rarefied gas is a function of the electromotive force acting to drive the current through it. I find that if the position of the sliding contact on the resistance across the terminals of the battery is so adjusted that corresponding thereto the conductivity curve of the ionized gas has a very sudden change in curvature, the superposition of an oscillatory potential difference between the filament and cylinder upon the steady potential difference causes very sudden changes in the current strength

through the telephone and therefore an emission of sound provided that the steady potential difference is of the necessary critical value. The arrangement described is therefore a very sensitive detector of oscillations in the condenser circuit to which the glow lamp is attached and therefore can serve as an electric wave detector in inductive or radiotelegraphy, since the sound in the telephone or indication of the equivalent current detector can be controlled from the transmitting end and cut up into Morse or other signals as required, to transmit by electric waves or magneto electric induction intelligence to a distance.

In the drawing accompanying and forming a part of this specification, I have illustrated one embodiment of my invention. Referring to this drawing it will be seen that in carrying my invention into effect I employ a tubular form of glass bulb *a* which may be an inch or more in diameter and five or six inches in length. In this I insert a cylinder *b* of carbon which is sprung into the glass tube so as to fit the walls tightly. This cylinder has a platinum wire *c* twisted or welded to it which is sealed through the glass, so as to make an external electrical connection. The bulb *a* should have a good vacuum such as is usually employed with lamps having metallic filaments. The metallic filament *d* is formed of tungsten in the form used as a filament in ordinary glow lamps and is connected to conductors *e* carried on a glass tubular stem *f* sealed into the bulb. The filament *d* should be of such a length that it is entirely covered by the metal cylinder *b*. It is convenient to have the filament of such length and thickness that the voltage required to bring it to incandescence at which its duration may not be less than several hundred hours, is of the order of 18 volts or so.

In applying this glow lamp as a detector in radiotelegraphy I arrange it as follows:—A battery *g* of secondary cells is provided which may conveniently be a dozen or more cells, and wires *h* are brought from the terminals of this battery to the terminals *e* of the filament of the lamp, a variable resistance *j k* being inserted in the circuit. It is convenient to divide this resistance into two, one namely *j* of from say 0 to 120 ohms being for coarse adjustment and the other *k* of from say 0 to 5 ohms being for fine adjustment. By means of these resistances the current of the lamp may be adjusted to have any required value. A voltmeter *l* should also be placed across the terminals of the filament to regulate the voltage. In addition I place across the terminals of the battery *g* a high resistance *m* of the potentiometer type, that is to say, a resistance which may be two or three hundred ohms or more, the terminals of which are connected to the terminals *h* of the battery. A double high resistance telephone *n* (the resistance of each telephone being at least five or six hundred ohms) has one terminal connected to a slider *o* which can make contact with any required point on the resistance *m* and the other terminal connected to one plate of a condenser *p*. The other plate of the condenser *p* is connected with the metal cylinder of the lamp. The condenser *p* is inserted in a circuit possessing inductance, which is directly or inductively connected with a receiving antenna. As shown the circuit connecting the two plates of the condenser *p* contains an adjustable inductance *q* and the secondary of the jigger *r* the primary of which is in the aerial *s*. When electric waves fall upon the receiving antenna they excite oscillations in the condenser circuit and oscillations are thus imposed upon the telephone circuit connecting the metal cylinder or plate in the lamp with the sliding contact and high resistance connected across the terminals of the battery or other source of continuous electric current.

In operating the arrangement, the first step is to bring the filament to a high incandescence at which it would be working approximately at one watt per candle and at which it will have such a temperature, approximately 2800° C., that it will diffuse into the vacuous space negative ions discharged from the incandescent filament. The filament having been rendered incandescent to this temperature, the observer applies the telephone to his ear and if electric wave trains are falling upon the receiving antenna *s*, it will be found that on moving the slider *o* along the potentiometer resistance *m* from one end to the other, there is a certain point at which sounds will be heard in the telephone better than at any other point. The exact position of the slider *o* must be determined by trial for it varies with every valve owing to slight differences in the vacuum and temperature of the filament. The detector above described is suitable as the receiver in radiotelephony, as well as for signals on the Morse or other alphabetic code.

What I claim is:—

1. A rectifier or valve for electric oscillations, having one electrode composed of tungsten.

2. A rectifier or valve for electric oscillations, having one electrode composed of tungsten and one element composed of carbon.

3. A rectifier or valve for electric oscillations, comprising a metallic filament constituting one electrode, means for heating said filament, and a plate of carbon constituting another electrode thereof.

4. A rectifier or valve for electric oscillations, comprising a metallic filament consti-

tuting one electrode, means for heating said filament, and a curved plate of carbon circumferentially situated in relation to the longitudinal axis of said filament.

5. An oscillation valve in which the hot conductor is a filament of tungsten.

6. An oscillation valve comprising a heated electrode in combination with a cold electrode consisting of a mass of carbon.

7. An oscillation valve comprising a heated electrode in combination with a cold electrode consisting of a cylinder of carbon.

8. An oscillation valve in which the hot conductor is a filament of tungsten and the cold conductor is a cylinder of carbon.

9. The combination of an oscillation valve, a source of electricity heating the filament of the valve, a resistance across the terminals of the source, a circuit connected at one end to the cold conductor of the valve and at the other to an adjustable point of the resistance, means for producing oscillations and means for detecting an electric current in the circuit.

10. In combination with an oscillation valve, a source of electric current for energizing the filament thereof, an oscillatory circuit having one terminal connected with one element of said oscillation valve, the other terminal of said oscillatory circuit being adjustably connected with a resistance which is connected with opposite terminals of another element of said valve, and a translating device operatively connected with said circuits for indicating the presence of electric oscillations.

JOHN AMBROSE FLEMING.

Witnesses:
GEO. J. B. FRANKLIN,
T. J. OSMAN.

PLAINTIFF'S EXHIBIT No. 213.

No. 879,532. PATENTED FEB. 18, 1908.

L. DE FOREST.

SPACE TELEGRAPHY.

APPLICATION FILED JAN. 29, 1907.

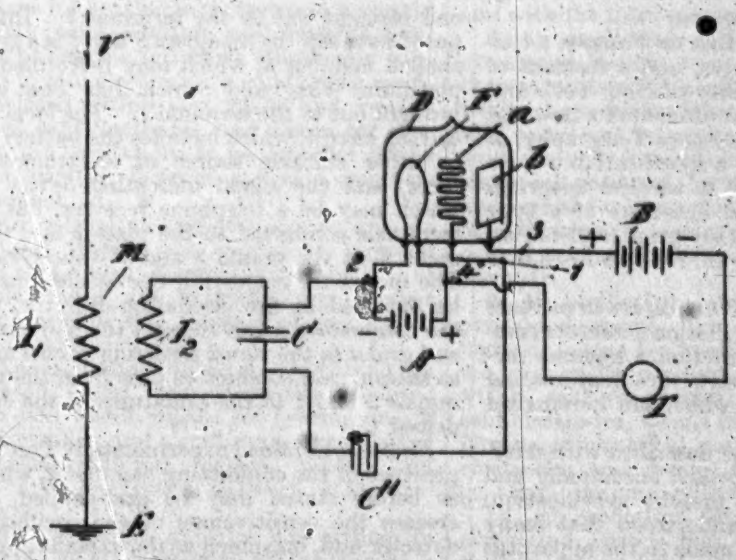


Fig. 1.

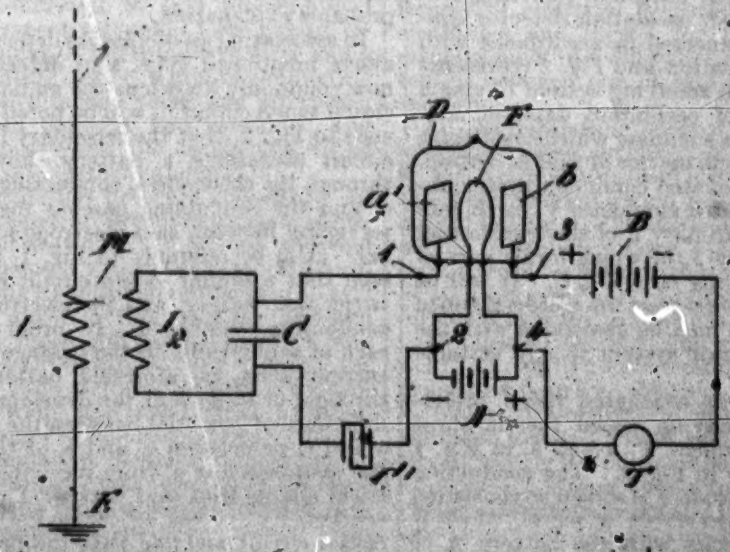


Fig. 2.

WITNESSES-
E. R. Tomlinson
Robt. F. Camp

INVENTOR
Lee de Forest
by Parker & Wordsworth

UNITED STATES PATENT OFFICE.

LEE DE FOREST, OF NEW YORK, N. Y., ASSIGNOR, BY MESNE ASSIGNMENTS, TO DE FOREST RADIO TELEPHONE CO., A CORPORATION OF NEW YORK.

SPACE TELEGRAPHY.

No. 879,532. Specification of Letters Patent. Patented Feb. 18, 1908.

Application filed January 29, 1907. Serial No. 354,063.

To all whom it may concern:

Be it known that I, LEE DE FOREST, a citizen of the United States, and a resident of New York, in the county of New York and State of New York, have invented a new and useful Improvement in Space Telegraphy, of which the following is a specification.

My invention relates to wireless telegraph receivers or oscillation detectors of a type heretofore described in my prior Letters Patent Nos. 824,637, June 26, 1906 and 836,070, November 13, 1906.

The objects of my invention are to increase the sensitiveness of oscillation detectors comprising in their construction a gaseous medium by means of the structural features and circuit arrangements which are hereinafter more fully described.

My invention will be described with reference to the drawings which accompany and form a part of the present specification, although it is to be understood that many modifications may be made in the apparatus and systems herein described without departing from the principles of my invention.

In the drawings, Figure 1 represents in diagram a wireless telegraph receiving system comprising an oscillation detector constructed and connected in accordance with the present invention and Fig. 2 represents a space telegraph receiving system having a modified form of oscillation detector connected therein in a manner which constitutes one of the subject matter of said invention.

V I, E is an elevated conductor system including the elevated conductor V, earth connection E, and primary I, of the transformer I, the secondary I, of which forms part of the tuned receiving circuit I, C. It will be understood of course that the aforesaid tuned receiving circuit may be associated with the elevated conductor system in any suitable manner.

D represents an evacuated vessel, preferably of glass, having sealed therein three conducting members, F, *a* and *b*, in Fig. 1 and F, *a'* and *b* in Fig. 2. The conducting member or electrode F is shown as consisting of a filament, preferably of metal, which is connected in series with the battery A or other source of electrical current of sufficient strength to heat said filament, preferably to incandescency. The conducting member *b*, which may be a plate of platinum, has one end brought out to the terminal 3. Interposed between the members F and *b* is a grid-shaped member *a*, which may be formed of platinum wire, and which has one end brought out to the terminal 1. The local receiving circuit, which includes the battery B, or other suitable source of electromotive force, and the signal indicating device T, which may be a telephone receiver, has its terminals connected to the plate *b* and filament F at the points 3 and 4 respectively. The means for conveying the oscillations to be detected to the oscillation-detector, are the conductors which connect the filament F and grid *a* to the tuned receiving circuit and, as shown, said conductors pass from the terminals 2 and 1 to the armatures of the condenser C.

I have determined experimentally that the presence of the conducting member *a*, which as before stated may be grid-shaped, increases the sensitiveness of the oscillation detector and, inasmuch as the explanation of this phenomenon is exceedingly complex and at best would be merely tentative, I do not deem it necessary herein to enter into a detailed statement of what I believe to be the probable explanation.

In associating an oscillation detector of the above mentioned type, said detector being now commonly known as the audion, with a closed tuned circuit, it will be noted by reference to Fig. 2, that the secondary I, closes a circuit containing a battery shown at B through the electrode *b*, conducting member *a'* and the conducting gaseous medium intervening between said electrode and member. Also by reference to Fig. 1, it will be seen that a similar closed circuit exists between said battery, and the electrode *b* and conducting member *a*. In order to close each of said circuits to the passage of direct current from the aforesaid battery therethrough, or to prevent the development of a difference of potential between the members *a* and *b*, or between *a'* and *b*, or to prevent the members *a* or *a'* from receiving an electrical charge from said battery, I insert the condenser C' in said otherwise mechanically closed circuit and find that the presence of said condenser produces a great increase in the sensitiveness of the oscillation detector as determined by the very marked increase in the sound produced in the telephone T

when said condenser is present over the sounds produced therein under the same conditions when said condenser is not employed.

It will be understood that the circuit arrangements herein described with reference to the particular forms of audion herein disclosed may with advantage also be employed with various other types of audion.

I claim.

1. An oscillation detector comprising an evacuated vessel, an electrode inclosed therein, means for heating said electrode, a second electrode inclosed within said vessel, a local circuit having its terminals electrically connected to said electrodes, a conducting member inclosed within said vessel and located between said electrodes, and means for conveying the oscillations to be detected to the first mentioned electrode and said conducting member.

2. An oscillation detector comprising an evacuated vessel, two electrodes inclosed within said vessel, means for heating one of said electrodes, and a conducting member inclosed within said vessel and interposed between said electrodes.

3. An oscillation detector comprising an evacuated vessel, two electrodes inclosed within said vessel, means for heating one of said electrodes, and a grid-shaped member of conducting material inclosed within said vessel and interposed between said electrodes.

4. An oscillation detector comprising an evacuated vessel, a filament sealed therein, a source of electrical energy connected in series with said filament, an electrode sealed in said vessel, a local circuit having its terminals connected to said filament and electrode, respectively, said local circuit including a source of electromotive force and a signal indicating device, a grid of conducting material sealed in said vessel and interposed between said filament and electrode, and means for conveying the oscillations to be detected to said filament and grid.

5. An oscillation detector comprising an evacuated vessel, an electrode inclosed therein, means for heating said electrode, a second electrode inclosed within said vessel, a local circuit having its terminals connected to said electrodes, a conducting member inclosed within said vessel and located between said electrodes, a closed circuit for conveying the oscillations to be detected to said first mentioned electrode and conducting member, and a condenser in said closed circuit.

6. An oscillation detector comprising an evacuated vessel, two electrodes inclosed therein, means for heating one of said electrodes, a conducting member inclosed within said vessel and interposed between said electrodes, means for establishing a difference of electrical potential between said electrodes and means for preventing said conducting member from becoming electrically charged.

7. An oscillation detector comprising an evacuated vessel inclosing a sensitive conducting gaseous medium, three conducting members inclosed therein, a closed oscillation circuit, a circuit connecting an element of said oscillation circuit with two of said members, a condenser in said circuit, a signal-indicating device, and a circuit connecting said device with one of said two members and with the third member.

8. An oscillation detector comprising an evacuated vessel, two electrodes inclosed therein, means for heating one of said electrodes, a conducting member inclosed within said vessel and interposed between said electrodes, means for establishing a difference of electrical potential between said electrodes and means for preventing the establishment of a difference of electrical potential between one of said electrodes and said conducting member.

9. An oscillation detector comprising an evacuated vessel, two electrodes inclosed therein, means for heating one of said electrodes, a grid of conducting material inclosed within said vessel and interposed between said electrodes, means for establishing a difference of electrical potential between said electrodes and means for preventing said grid from becoming electrically charged.

10. An oscillation detector comprising an evacuated vessel, two electrodes inclosed therein, means for heating one of said electrodes, a grid of conducting material inclosed within said vessel and interposed between said electrodes, means for establishing a difference of electrical potential between said electrodes and means for preventing the establishment of a difference of electrical potential between one of said electrodes and said grid.

11. An oscillation detector comprising an evacuated vessel, an electrode inclosed therein, means for heating said electrode, a second electrode inclosed within said vessel, a local circuit having its terminals electrically connected to said electrodes, a grid of conducting material inclosed within said vessel and located between said electrodes, and means for conveying the oscillations to be detected to the heated electrode and grid.

12. An oscillation detector comprising an evacuated vessel, an electrode inclosed therein, means for heating said electrode, a second electrode inclosed within said vessel, a local circuit having its terminals connected to said electrodes, a grid of conducting material inclosed within said vessel and located between said electrodes, a closed circuit for conveying the oscillations to be detected to the heated electrode and grid, and a condenser in said closed circuit.

13. An oscillation detector comprising an

evacuated vessel, an electrode inclosed therein, means for heating said electrode, a second electrode inclosed within said vessel, a local circuit having its terminals electrically connected to said electrodes, said local circuit including a source of electromotive force and a signal indicating device, a grid of conducting material inclosed within said vessel and located between said electrodes, and means for conveying the oscillations to be detected to the heated electrode and grid.

14. An oscillation detector comprising an evacuated vessel, two electrodes, one of which is a filament, inclosed within said vessel, means for heating said filament, and a conducting member inclosed within said vessel and interposed between said electrodes.

15. An oscillation detector comprising an evacuated vessel, two electrodes inclosed within said vessel, means for heating one of said electrodes, a grid of conducting material inclosed within said vessel and interposed between said electrodes, a local circuit connecting said electrodes, and a source of electromotive force and signal indicating device in said local circuit.

16. An oscillation detector comprising an evacuated vessel, two electrodes, one of which is a filament, inclosed within said vessel, means for heating said filament, and a grid of conducting material inclosed within said vessel and interposed between said electrodes.

17. An oscillation detector comprising an evacuated vessel, two electrodes inclosed within said vessel, means for heating one of said electrodes, a conducting member inclosed within said vessel and interposed between said electrodes, and a local circuit including a source of electromotive force connecting said electrodes.

18. An oscillation detector comprising an evacuated vessel, two electrodes inclosed within said vessel, means for heating one of said electrodes, a grid of conducting material inclosed within said vessel and interposed between said electrodes, a local circuit including a source of electromotive force connecting said electrodes and a signal indicating device associated with said local circuit.

19. An oscillation detector comprising an evacuated vessel, two electrodes, one of which is a filament, inclosed within said vessel, means for heating said filament, a grid of conducting material inclosed within said vessel and interposed between said electrodes and a local circuit including a source of electromotive force connecting said electrodes.

20. An oscillation detector comprising an evacuated vessel, two electrodes inclosed therein, means for heating one of said electrodes, a conducting member inclosed within said vessel, a closed oscillation circuit, a circuit connecting one element of said oscillation circuit with one of said electrodes and said conducting member, and a condenser in said circuit.

21. An oscillation detector comprising an evacuated vessel, two electrodes inclosed therein, means for heating one of said electrodes, a conducting member inclosed within said vessel, a closed oscillation circuit, a circuit connecting one element of said oscillation circuit with one of said electrodes and said conducting member, a condenser in said circuit, a signal indicating device and a circuit connecting said device with the other of said electrodes and said conducting member.

In testimony whereof, I have hereunto subscribed my name this 21st day of Dec. 1906.

LEE DE FOREST.

Witnesses:

THOMAS I. GALLAGHER,

HANS W. GOETZE.

PLAINTIFF'S EXHIBIT No. 214.

Modification
OF
License Agreement

Dated July 1, 1920

GENERAL ELECTRIC COMPANY

AND

AMERICAN TELEPHONE AND TELEGRAPH COMPANY

July 1, 1926

AGREEMENT dated July 1, 1926, between GENERAL ELECTRIC COMPANY, a New York corporation (herein called the General Company), and AMERICAN TELEPHONE AND TELEGRAPH COMPANY, a New York corporation (herein called the Telephone Company).

WHEREAS, the parties hereto heretofore entered into an agreement made the first day of July, 1920, granting certain reciprocal licenses primarily in respect of electrical apparatus, but because at said date the art in certain of the fields dealt with in said agreement had not progressed to a point at which it was possible fully to comprehend the problems involved, disputes have arisen between the parties as to the meaning of various provisions of said agreement; and

WHEREAS, certain provisions of said agreement are not, as a practical matter, workable in the present state of the art; and

WHEREAS, unless said disputes are settled and said agreement made workable in practice progress in the fields dealt with in said agreement will be greatly hampered and delayed, and the parties desire to modify said agreement for the purpose of settling said disputes and making said agreement workable in practice;

Now, in consideration of the premises and the mutual agreements herein contained, the parties agree each with the other as follows:

I. Said agreement made the first day of July, 1920, shall be and is modified to read as follows:

AGREEMENT made the first day of July, 1920, between General Electric Company, a New York corporation (herein called the General Company), and American Telephone and Telegraph Company, a New York corporation (herein called the Telephone Company).

WHEREAS, the General Company is engaged in the manufacture and sale in the United States of apparatus and systems for the generation, distribution and utilization of electricity for light, heat, power, traction and associated purposes, and in the manufacture and sale of a general line of electrical and power apparatus, and, directly and through subsidiaries, is engaged in the pur-

chase of apparatus of various kinds from others and in the sale thereof; and is also engaged in the manufacture and sale of wireless apparatus; and

WHEREAS, the Telephone Company and the Companies of the Bell System and their subsidiaries are engaged in the operation of telephone and telegraph systems and in the manufacture, purchase and sale of telephone and telegraph and other electrical apparatus; and

WHEREAS, each party is in possession of information, patents and inventions applicable to, and has research organizations engaged in investigations bearing upon, not only its own business but also the business of the other party; and

WHEREAS, various patents or applications for patents of the parties are involved in interference with each other in the United States Patent Office; and

WHEREAS, the restrictions upon each party imposed by the patent rights of the other and the uncertainties arising out of interferences have tended to, and if permitted to continue, will hamper and delay, progress in the development and production of wire and wireless telephone and telegraph and phonograph apparatus and systems; and

WHEREAS, the effective and prompt development of the arts in question can be secured only by the free and frank co-operation and exchange of information between the parties, which can not well take place if improvements and knowledge resulting from one party's co-operation with the other party may without its consent be made available in its field to the use of others;

Now, in consideration of the premises and the mutual agreements herein contained, it is agreed as follows:

ARTICLE 1.

DEFINITIONS.

For the purposes of this agreement the following terms are defined as follows:

"*Wire telephony*" is the art of communicating or reproducing sound waves (created, directly or indirectly,

by the voice or by musical instruments) by means of electricity, magnetism or electro-magnetic waves, variations or impulses conveyed or guided by wires, and includes all generating, measuring, switching, signaling and other means or methods incidental to or involved in such communication.

"Wireless telephony" has the same meaning as "wire telephony", except that the waves, variations or impulses are radiated through space.

"Wire telegraphy" is the art of communicating messages by code signals (such as the Morse Code, for example) and of picture transmission, by means of electricity, magnetism or electro-magnetic waves, variations or impulses conveyed or guided by wires, and includes all generating, measuring, switching, signaling and other means or methods incidental to or involved in such communication, but does not include such devices as annunciators, elevator signals, engine room telegraphs, etc.

"Wireless telegraphy" has the same meaning as "wire telegraphy," except that the waves, variations or impulses are radiated through space.

"Picture transmission" is the art of transmitting, or receiving at another point than the point of transmission, by means of electricity, magnetism or electro-magnetic waves, variations or impulses, the aspect or shape of things, including pictures, whether still or moving, drawings, writings, forms and other graphic, printed and written matter of all kinds, and includes television.

"Programs" means pictures, news, music, speeches, sermons, advertising and entertainment, educational and similar matter, or any of them or combinations of any of them, for the purpose of exhibition, entertainment or instruction.

"Power purposes" means all prime movers and their accessories and all generation, use, measurement, control and application of electricity for light, heat, power and traction, but does not include any communication purpose.

"Public address system" means a combination of one or more telephone transmitters and one or more loud speaking telephone receivers, either adjacent to said transmitters or at a distance therefrom, opefating by one-way wire telephony for the reproduction of sound with increased volume, but does not include apparatus for operation in combination or connection with or as parts of apparatus for (1) wireless telephone reception, or (2) reception of programs over electric light, electric heat, electric power or electric traction lines, or (3) the production or reproduction of sound from sound records.

"Phonographs" means all apparatus for the reproduction of sound from sound records used in or in connection with such apparatus, to be heard in the immediate vicinity of the apparatus, but does not include apparatus for the transmission to, or reception at, other points of sound reproduced from such records.

"Electric Phonograph" means a phonograph in which the sound record used therein gives rise to or controls an electric current or electromotive force in such a way that the variations of the electric current or electromotive force correspond in some way to the recorded sounds, and the electric current or electromotive force directly or indirectly brings about the production of the sound from the phonograph.

"Transoceanic" communication means all communication which crosses any ocean, gulf or sea between two continents, or between a continent and an island more than one hundred miles from its shores (islands within one hundred miles of the shores of a continent being considered parts thereof), or between two islands which are not parts of the same continent, except that communication between ships or aircraft, between ships and aircraft, or between ships or aircraft and shore, and communication between parts of the same continent, is not transoceanic communication. North America, including the Panama Canal Zone and all of Central America north thereof, is to be considered as one continent, and South America and all of Central America south of the Panama Canal Zone as another.

"The United States Government" means not only the Federal Government but also the Governments of the Philippines, Porto Rico and other federal possessions, present or future; but does not include any municipal, county or state government.

"Train dispatching" is telegraphic or telephonic conveyance of train orders or operating information between the office of a train dispatcher or similar official and railway trains or other automotive land vehicles (not including air planes or airships) or points along the line of way, for directing the movements of such automotive vehicles.

"Railway signalling" is the operation of signals, switches, brakes, stops, crossing gates, etc., controlling or signalling the movements of trains or other automotive vehicles, controlled by or in accordance with train or vehicle movements or track conditions, including block signalling, cab signals and train stops. It does not include train dispatching.

"Apparatus" includes machines, devices and appliances and the materials entering into the construction thereof.

"Household devices" are electric or electrically operated apparatus, not herein otherwise specified, designed primarily for domestic use, but do not include apparatus for communication purposes.

"Homes" means all places of residence, permanent or temporary, including, however, as to hotels, hospitals and club houses only the private living rooms thereof.

"Amateur" means one, not a professional investigator, who is more than a mere broadcast listener and who evidences his interest in the art of wireless telephony by study, investigation or experiment in the art.

"Subsidiaries" of either party are corporations a majority of whose stock having power to vote for the election of directors is owned, directly or indirectly, either by such party, or by such party and one or more of its other subsidiaries, or by one or more of its other subsidiaries. The party hereto so controlling, directly or indirectly, any subsidiary is herein called the *"parent company"* of such subsidiary.

"Companies of the Bell System" are those companies which, in connection directly or indirectly with the Telephone Company, provide a telephone service throughout the United States, or from the United States to foreign countries. These companies at present comprise the Telephone Company, Western Electric Company, Incorporated, Cuban American Telephone and Telegraph Company, and the so-called Associate Companies and Connecting Companies, and their several subsidiaries.

Any dispute arising as to the meaning or application of the foregoing definitions shall be settled by arbitration, as hereinafter provided.

ARTICLE II.

THE PATENTS INCLUDED IN THIS AGREEMENT.

The licenses provided for herein are granted and agreed to be granted under all patents, and rights to or under patents, of the United States now or hereafter during the term of this agreement owned or controlled by the parties hereto, and under all such patents hereafter issued upon inventions now or hereafter during said term so owned or controlled, and to the extent to which the parties have or may have the right to grant licenses, in so far as the inventions covered by such patents are or shall be applicable to the respective fields for which said licenses are expressed as granted or to be granted, excepting (1) as otherwise specified in connection with the several grants hereinafter contained, and (2) such patents and inventions as may hereafter be excluded from the operation of this agreement in the following manner:

A list of all United States patents under which it now holds transferable rights shall be furnished by each party to the other within sixty days from the date of this agreement. Such lists shall separately identify those patents, and shall also include those applications, as to which rights, if granted hereunder, would be restricted in scope or would involve continuing obligations not implied by law. Copies of all contracts creating such restrictions or obligations shall, upon request, be furnished by each party to the other. Thereupon, and within six months after the receipt of the lists to be

furnished as aforesaid, each party may in writing advise the other as to the patents and applications described in such list, furnished by the other, which (or the patents to issue on which) it desires to exclude from this agreement; and no licenses are granted by this agreement under any patents so excluded.

Each party shall thereafter, at such periods as may be agreed upon, or whenever requested by the other party, furnish to such other party like lists of subsequent patents and applications, and upon request therefor like copies of contracts; and each party may, within six months after the receipt of any such list, advise the other in writing as to the patents and applications described in such list which (or the patents to issue on which) it desires to exclude from this agreement; and no licenses are granted by this agreement under any patents so excluded.

ARTICLE III.

SCOPE OF LICENSES.

1. All of the licenses herein granted are, unless otherwise expressed in connection with the several grants, licenses to use methods and processes, and to make, use, sell, lease or otherwise dispose of apparatus and systems in the fields in which the licenses are granted.

2. A license to make apparatus includes a license to have such apparatus manufactured for the licensee by others, subject to the provisions of this article III and article X of this agreement. No rights are granted to either party to manufacture or to have manufactured, under patents under which it receives licenses hereunder, apparatus of the character at the time manufactured by the other party, except in factories owned or operated by one or the other of the parties hereto, or by their subsidiaries, without the written consent of the party granting such licenses.

3. Every license herein granted to either party includes, unless otherwise herein provided, all incidental rights necessary to the full enjoyment and exercise of the license granted, notwithstanding that such incidental

rights may lie primarily in a field in which the other party is herein granted a license which is denominated exclusive.

4. The making, using, selling, leasing or otherwise disposing of parts is subject to the same restrictions and conditions as are applicable under this agreement to apparatus of which they are or may be parts.

ARTICLE IV.

RESERVATIONS AND EXCEPTIONS TO WHICH THE LICENSES ARE SUBJECT

1. Each party reserves, under its own patents, a non-exclusive right to make for and sell or lease to the United States Government wireless apparatus and systems for use only for other than commercial or toll purposes, and to grant to that government non-exclusive licenses to make or have made for it and to use wireless apparatus and systems, but only for other than commercial or toll purposes; and all exclusive licenses herein granted are subject to this reservation.

2. Each party reserves, under its own patents, rights in the fields and for the purposes with reference to which, and to the extent to which, it receives licenses under patents of the other party.

3. All exclusive licenses herein granted to either party are subject to licenses specifically herein granted to the other party and to rights incidental to the full enjoyment and exercise of all licenses granted to the other party, except as herein otherwise expressly provided.

4. No licenses are granted by either party with reference to the manufacture or sale of wire or cable for the transmission of electric current for light, heat, traction or other power purposes, or for telephone or telegraph purposes.

5. No licenses are granted to the Telephone Company for electric lamps or other lighting apparatus (except non-exclusive licenses with reference to telephone and telegraph signal lamps and telephone and telegraph ballast lamps for use solely in fields in which the Telephone Company is otherwise licensed under this agreement), nor for the working of tungsten. But the Tele-

phone Company is licensed to use, in the fields for which it receives licenses hereunder, tungsten purchased from the General Company, or from others having the right to make and sell tungsten, and to make, use, sell or lease (for such fields only) devices embodying such tungsten. The General Company agrees to sell and deliver such tungsten for such purposes, in wire or other practicable form to be specified by the purchaser from time to time, on the terms specified in article X hereof.

The Telephone Company agrees that, on all sales of telephone and telegraph signal lamps or telephone and telegraph ballast lamps, hereunder, to others than Companies of the Bell System, (other than lamps licensed under paragraph (*d*) of subdivision C of section 4 of article V hereof), it will pay to the General Company a royalty of 2% on the net sales price thereof.

6. The licenses herein granted to the Telephone Company, in so far as they cover rights to sell or lease carrier current, wireless or vacuum tube apparatus for use on electric railroads, are limited to sales or leases of said apparatus to the railroads; the sale of such apparatus to be installed in electric cars and electric locomotives designed or built by the General Company, as part of the original construction and equipment thereof, shall be through the General Company only.

ARTICLE V.

LICENSES GRANTED.

Subject to the foregoing reservations, each party grants and agrees to grant to the other the following licenses in the following fields of use:

1. Government Uses.

Each party grants to the other non-exclusive licenses to make for, and sell or lease to, the United States Government wireless apparatus and systems for use only for other than commercial or toll purposes.

2. Wireless Telegraphy.

(*a*) The General Company grants to the Telephone Company licenses in the field of wireless telegraphy, exclusive except as in this paragraph (*a*) provided, for combined wireless telephone and telegraph sets for use

on ships; but where such combined sets are for use on ocean-going and coastwise ships of American registry (excluding harbor tug-boats and other harbor craft) the exclusive right to use, lease, sell or otherwise dispose of the same is granted by the Telephone Company to the General Company. The Telephone Company agrees upon request to make such sets and sell them for such use to the General Company upon reasonable terms.

(*b*) The General Company grants to the Telephone Company non-exclusive licenses in the field of wireless telegraphy to make and use (but not to sell, lease or otherwise dispose of, except to Companies of the Bell System) apparatus and systems for its own communication or that of Companies of the Bell System, and for use solely as an incidental facility in fields in which it is otherwise licensed under this agreement, but not for transmission of messages for the public except temporarily in emergencies due to storms or other catastrophes.

(c) The General Company grants to the Telephone Company non-exclusive licenses in the field of wireless telegraphy to make and use (but not to sell, lease or otherwise dispose of, except leases to subscribers in connection with a service given by Companies of the Bell System in the paragraph described) apparatus and systems for the purpose of giving within the continental United States, and between the continental United States and other parts of continental North America, a business, commercial or official service limited to a particular customer or class of customers and analogous to the service given by Companies of the Bell System by wire telegraphy at the date of this agreement, commonly designated as leased wire or special contract service, but said licenses do not include the making or using of such apparatus for (1) transmission or reception for the public generally or (2) transoceanic communication or (3) transmission or reception of programs; and the licenses granted to, and the rights reserved by, the Telephone Company for the purposes covered by this paragraph (*c*) include only apparatus for the reception of such service which shall be adapted for reception only upon the wave lengths (not exceeding as to any set three specific wave lengths) upon which such service is given.

(*d*) The General Company grants to the Telephone Company non-exclusive licenses in the field of wireless telegraphy to make and use (but not to sell, lease or otherwise dispose of, except to Companies of the Bell System) apparatus and systems for television for use solely in combination with apparatus and systems for two-way telephony for the purpose of giving a public service combining television and speech, but said licenses do not include the making or using of such apparatus for transmission or reception of programs.

(*e*) The General Company grants to the Telephone Company non-exclusive licenses in the field of wireless telegraphy for combined wireless telephone and telegraph sets, other than sets for transoceanic communication, (1) for use in communication by, with and between airplanes, airships and other automotive devices other than ships and railway vehicles, and (2) for export from the continental United States for use for any purpose other than transoceanic communication.

(*f*) Subject to non-exclusive rights reserved for the purposes described in paragraphs (*b*), (*c*), (*d*) and (*e*) of this section 2, the Telephone Company grants to the General Company exclusive licenses for all purposes in the field of wireless telegraphy other than for the purposes covered by paragraph (*a*) of this section 2 and by section 8 of this article V.

(*g*) The licenses granted to the General Company in this section 2 do not cover the use of wireless telegraph stations for giving a telephone service, except as licensed in section 4 of this article V. The General Company agrees that the surplus facilities of said stations of the General Company shall, upon request of the Telephone Company, be made available to the Telephone Company or its sub-licensees, upon reasonable terms to be agreed upon by the parties, for giving a two-way telephone service; and it shall be a condition of every sub-license granted by the General Company under the licenses granted to it in this section 2 that the sub-licensee shall be under like obligation in respect of its wireless telegraph stations embodying any invention in respect of which it is granted such sub-license.

3. Wire Telegraphy.

(*a*) The Telephone Company grants to the General Company exclusive licenses in the field of wire telegraphy for the transmission and reception of programs over electric light, electric heat, electric power and electric traction lines, subject, however, to the provisions of paragraph (*b*) of section 5 of this article V regarding electrical interference.

(*b*) The Telephone Company grants to the General Company non-exclusive licenses in the field of wire telegraphy to make (but not to sell, lease or otherwise dispose of) apparatus and systems, and (1) to use such apparatus and systems for its own communication and for use solely as an incidental facility in fields in which it is otherwise licensed under this agreement, and (2) to use such apparatus and systems upon wire telegraph systems owned by it, or leased to it for its operation (other than transoceanic cables), for all purposes other than giving a service by wire telegraphy analogous to the service given by the Companies of the Bell System by wire telegraphy at the date of this agreement, commonly designated as leased wire or special contract service, and other than train dispatching; but no licenses are granted with reference to transoceanic wire telegraphy.

(*c*) The Telephone Company grants to the General Company non-exclusive licenses in the field of wire telegraphy for apparatus and systems for communication only in connection with the operation of apparatus for power purposes, but not for transmission of messages for the public.

(*d*) The Telephone Company grants to the General Company non-exclusive licenses in the field of wire telegraphy for apparatus and systems for communication between parts of a train (without regard to the nature of the motive power thereof), or between trains following or approaching each other upon the same system of tracks, or between trains approaching a cross-over or junction point of the systems of tracks upon which they are running, or between trains and signal towers or way-stations within short distances thereof, but in each in-

stance only for use in connection with the operation of such trains but not for train dispatching.

(*e*) Subject to non-exclusive rights reserved for the purposes described in paragraph (*b*), (*c*) and (*d*) of this section 3, the General Company grants to the Telephone Company exclusive licenses for all purposes in the field of wire telegraphy (other than that covered by paragraph (*a*) of this section 3) on land, and over ocean cables not more than one hundred miles in length, and between the main body of the United States and Cuba; but no licenses are granted with reference to other transoceanic wire telegraphy.

4. Wireless Telephony.

A. IN GENERAL.

(*a*) The Telephone Company grants to the General Company non-exclusive licenses in the field of wireless telephony to make and use (but not to sell, lease or otherwise dispose of) apparatus and systems for its own communication and for use solely as an incidental facility in fields in which it is otherwise licensed under this agreement, but not for transmission of messages (as distinguished from programs) for the public except temporarily in emergencies due to storms or other catastrophes.

(*b*) The Telephone Company grants to the General Company exclusive licenses in the field of amateur wireless telephony, subject to non-exclusive rights reserved for the purposes and subject to the limitations hereinafter in this paragraph (*b*) provided; and the General Company grants to the Telephone Company non-exclusive licenses to make and sell apparatus in the field of amateur wireless telephony limited as hereinafter in this paragraph (*b*) provided. The licenses by this paragraph (*b*) granted by the Telephone Company to the General Company shall be free of royalties, but all apparatus sold by the Telephone Company under the licenses granted by this paragraph (*b*) shall be treated as if such apparatus were apparatus for one-way wireless telephone reception of programs under the provisions of paragraph (*d*) of subdivision C of this section 4 and

shall be governed by all the provisions of said paragraph (*d*).

(*c*) Each party grants to the other non-exclusive licenses for headphones for all purposes in all fields covered by this agreement; provided, however, that headphones sold by the Telephone Company as part of complete apparatus for one-way wireless telephone reception of programs shall be included in the determination of the royalties payable by the Telephone Company under the provisions of paragraph (*d*) of subdivision C of this section 4.

(*d*) Each party grants to the other non-exclusive licenses in the field of wireless telephony for apparatus and systems for communication only in connection with the operation of apparatus for power purposes, but not for transmission of messages for the public.

(*e*) Each party grants to the other non-exclusive licenses in the field of wireless telephony for apparatus and systems for communication between parts of a train (without regard to the nature of the motive power thereof), or between trains following or approaching each other upon the same system of tracks, or between trains approaching a cross-over or junction point of the system of tracks upon which they are running, or between trains and signal towers or way-stations within short distances thereof, but in each instance only for use in connection with the operation of such trains but not for train dispatching.

B. TWO-WAY WIRELESS TELEPHONY.

(*a*) The General Company grants to the Telephone Company exclusive licenses in the field of two-way transoceanic wireless telephony to make and use (but not to sell, lease or otherwise dispose of) apparatus and systems for use in the continental United States; but such licenses do not include use for transmission or reception of messages offered for telephonic transmission.

(*b*) The General Company grants to the Telephone Company non-exclusive licenses in the field of two-way transoceanic wireless telephony, to make and sell to stations outside the continental United States engaged in

cooperation with the Telephone Company in giving for the public a transoceanic telephone service, apparatus for use in giving such service; and subject to non-exclusive rights reserved for the purposes described in the foregoing clause of this paragraph (*b*), the Telephone Company grants to the General Company exclusive licenses in the field of two-way transoceanic wireless telephony for apparatus for export from the continental United States.

(*c*) The Telephone Company grants to the General Company non-exclusive licenses in the field of two-way wireless telephony for combined wireless telephone and telegraph sets, other than sets for transoceanic communication, (1) for use in communication by, with and between airplanes, airships and other automotive devices other than ships and railway vehicles, and (2) for export from the continental United States for use for any purpose other than transoceanic communication.

(*d*) Subject to non-exclusive rights reserved for the purposes described in paragraph (*c*) of this subdivision B, the General Company grants to the Telephone Company exclusive licenses in the field of two-way wireless telephony (other than in the field of transoceanic wireless telephony) for all purposes other than the purposes covered by subdivision A of this section 4.

(*e*) The licenses granted to the Telephone Company in this subdivision B do not include the use of wireless telephone stations for giving a telegraph service, except as licensed in section 2 of this article V. The Telephone Company agrees that the surplus facilities of said stations of the Telephone Company shall, upon request of the General Company, be made available to the General Company or its sub-licensees, upon reasonable terms to be agreed upon by the parties, for giving a wireless telegraph service; and it shall be a condition of every sub-license granted by the Telephone Company under the licenses granted to it in this subdivision B that the sub-licensee shall be under like obligation in respect of its wireless telephone stations embodying any invention in respect of which it is granted such sub-license.

C. ONE-WAY WIRELESS TELEPHONY.

(*a*) Each party grants to the other non-exclusive licenses in the field of one-way wireless telephony for apparatus and systems for the purpose of giving a business, commercial or official service limited to a particular customer or class of customers; but the licenses granted by this paragraph (*a*) do not include the making or using of such apparatus for (1) transmission or reception of messages for the public generally or to transmission or reception of programs; and the licenses granted to, and the rights reserved by, the Telephone Company for the purposes covered by this paragraph (*a*) include only apparatus for the reception of such service which shall be adapted for reception only upon the wave lengths (not exceeding as to any set three specific wave lengths) upon which such service is given and only apparatus for the transmission of such service from and within the continental United States.

(*b*) Each party grants to the other non-exclusive licenses in the field of one-way wireless telephony for apparatus and systems for use for transmitting for purposes other than that covered by paragraph (*a*) of this subdivision C, including, however, apparatus for wireless telephone reception furnished as a part of the equipment of transmitting stations; but the licenses granted by this paragraph (*b*) do not include apparatus in the field of amateur wireless telephony.

(*c*) The General Company grants to the Telephone Company non-exclusive licenses to make and use (but not to sell, lease or otherwise dispose of, except to Companies of the Bell System) apparatus for one-way wireless telephone reception (including apparatus for the reception of programs) for its own communication or that of Companies of the Bell System, and for use solely as an incidental facility in fields in which it is otherwise licensed under this agreement.

(*d*) The General Company grants to the Telephone Company non-exclusive licenses to make and sell (but not to lease or otherwise dispose of) apparatus for one-way wireless telephone reception of programs, but not for use in combination or connection with phonographs; provided, however, that the licenses granted in this para-

graph (*d*) shall be subject to the following terms and conditions:

(1) Tubes (thermionic devices) sold as separate devices for use in apparatus covered by this paragraph (*d*), or in apparatus which under other provisions of this agreement shall be treated as apparatus covered by this paragraph (*d*), shall be free of royalties to the amount of $2,000,000 during each calendar year, and said tubes in excess of said amount in any year shall be subject to a royalty of fifty per cent. computed as hereinafter provided; provided that in no event shall tubes sold free of royalty exceed 1,000,000 in number during any calendar year; and provided further that where said tubes are sold as parts of receiving sets or other complete units designed for operation with such sets, such tubes shall be treated as parts of the receiving set or other unit and shall not be classified under this subparagraph (1).

(2) Receiving sets and apparatus which under other provisions of this agreement shall be treated as apparatus covered by this paragraph (*d*), or parts thereof (including loud speakers, amplifiers and tubes other than thermionic devices), shall be free of royalty to the aggregate amount of $3,000,000 in each calendar year, and such sets, apparatus or parts in excess of said amount shall be subject to a royalty of fifty per cent. computed as hereinafter provided; provided that if the sales of tubes sold as separate devices amount to less than $2,000,000 during any year, the amount of such deficiency shall be added to the amount of receiving sets, apparatus and parts which may be sold free of royalty in the same year.

(3) For any portion of the first or last calendar year of this agreement, less than an entire calendar year, during which royalties shall be payable hereunder, the amounts which may be sold free of royalty shall be that proportion of the amounts which may be sold free of royalty in the entire calendar year which said fractional part of a calendar year bears to a calendar year.

(4) The licenses granted to the Telephone Company in this paragraph (*d*) to sell apparatus for one-way wireless telephone reception of programs (and the licenses

to sell apparatus which under other provisions of this agreement shall be treated as apparatus covered by this paragraph) are licenses for sale only at retail (except as to sales for export), either directly or through the Telephone Company's own direct agents and are subject to the condition that the Telephone Company shall retain in itself, or in one or more of its subsidiaries, title to the apparatus and control of its disposition until it is so sold.

(5) The aforementioned amounts sold free of royalty, and the amounts subject to royalty, shall (except as to sales for export) be based on the actual price at which the apparatus is sold at retail.

(6) Sales for export shall be included in determining the amounts sold free of royalty, and the amounts subject to royalty, on the basis of the price at which the sale is made.

(7) In ascertaining the amount of the sales which are free from royalty and the amount of the sales upon which royalties are to be paid hereunder, where apparatus is sold any part of which embodies any invention of any of the patents included in this agreement, the selling price of the apparatus sold shall be taken as the basis; but apparatus not covered by any of the patents of the parties, when sold not assembled for operation with apparatus covered by such patents, shall not be taken into account in computing the amounts of sales which are free from royalty or the amount of sales which are subject to royalty, unless such apparatus not covered by such patents is adapted for operation with apparatus covered by such patents and is sold in such manner that its sale or its use in connection with apparatus covered by such patents would, except for the licenses granted by this agreement, constitute contributory infringement of patents of the parties under which exclusive licenses are granted to the General Company by this agreement. Where radio receiving sets are sold for use in combination with apparatus primarily designed as public address systems the sale price of the public address apparatus shall not be included in the amount of the sales which are free from royalty or the amount of the sales which are subject to royalty. Chem-

ical primary batteries, wet or dry, and chemical storage batteries, not sold as part of apparatus upon which royalties are payable hereunder, or wiring in a building in connection with a sale of such apparatus, shall not be taken into account in computing the amount of sales which are free from royalty or the amount of sales which are subject to royalty.

(*e*) Subject to non-exclusive rights reserved for the purposes covered by paragraphs (*b*), (*c*) and (*d*) of this subdivision C, the Telephone Company grants to the General Company exclusive licenses for apparatus and systems for one-way wireless telephone reception of programs.

(*f*) Subdivision A of this section 4 and paragraphs (*a*) to (*e*), inclusive, of this subdivision C are intended to make provision for all anticipated fields of use of apparatus for one-way wireless telephone reception. If it should develop that there are other fields of use of such apparatus not covered herein licenses shall be granted in such other fields of use to the respective parties in accordance with the principle underlying said other paragraphs of this subdivision C, with special reference to the interest of the General Company in the field of one-way wireless telephone reception of programs, on the one hand, and of the Telephone Company in the field of one-way wireless telephone reception for giving a service of a business, commercial or official nature, on the other hand. If the parties can not agree with respect to such licenses, their respective rights shall be determined by arbitration in accordance with the provisions of article XIII.

5. Wire Telephony.

(*a*) The Telephone Company grants to the General Company exclusive licenses, subject to non-exclusive rights reserved for the same purposes, and the General Company grants to the Telephone Company non-exclusive licenses, in the field of wire telephony for apparatus for carrier current telephone communication, both one-way and two-way, over electric light, electric heat, electric power and electric traction lines, or partly over such lines and partly across wireless gaps, but in each instance only for the use of the owner or operator of such line.

in the business of such owner or operator, and not for transmission of messages for the public except temporarily in emergencies due to storms or other catastrophes.

(*b*) The Telephone Company grants to the General Company exclusive licenses in the field of one-way wire telephony for apparatus for the transmission and reception of programs over electric light, electric heat, electric power and electric traction lines including the use of such lines for pick-up lines or for connecting two or more separate electric systems in connection with the transmission or reception of programs over such lines or by means of wireless telephony, but not including the use of other wires for such purposes except as licensed in paragraph (*c*) of this section 5; provided, however, that no apparatus is licensed under this paragraph (*b*), or under paragraph (*a*) of section 3 of this article V, the use of which would electrically interfere unreasonably with the Telephone Company's systems of wire communication for which it is licensed under this agreement, as the same may now exist or may hereafter normally be developed, or with the Telephone Company's exclusive field of transmitting programs by wire telephony over lines other than electric light, electric heat, electric power and electric traction lines, and the Telephone Company shall be the sole judge of the existence of such unreasonable interference. The Telephone Company agrees whenever requested by the General Company, but at the expense of the General Company consented to by it before being incurred, to co-operate with the General Company in every reasonable way to enable the General Company to develop apparatus within the licenses granted by this paragraph (*b*) which will avoid such electrical interference.

(*c*) The Telephone Company grants to the General Company non-exclusive licenses in the field of wire telephony, both one-way and two-way, to make (but not to sell, lease, or otherwise dispose of) apparatus and systems, and to use such apparatus and systems solely upon systems owned by it, for its own communication and for use solely as an incidental facility in fields in which it is otherwise licensed under this agreement, but

not for transmission of messages (as distinguished from programs) for the public except temporarily in emergencies due to storms or other catastrophes. The Telephone Company agrees to furnish to the General Company, when requested, pick-up or connecting wires, if available, for its use in the transmission of programs to or from its stations for such transmission either by means of wireless telephony or over electric light, electric heat, electric power and electric traction lines, or for its use in electrical sound recording, on terms at least as favorable as the terms given to others than the General Company, and agrees that in furnishing such pick-up and connecting wires for such service there shall be no discrimination against the General Company; and, in addition to and without limitation of the licenses granted by the foregoing clauses of this paragraph (*c*), the General Company reserves non-exclusive rights in the field of wire telephony under its own patents only, for use in connection with providing for itself or obtaining from others such service or facilities if the Telephone Company shall in any case fail to furnish the same, and the non-exclusive rights so reserved may be assigned to or otherwise availed of by any other party from which the General Company shall obtain service or facilities.

(*d*) The Telephone Company grants to the General Company non-exclusive licenses in the field of wire telephony for apparatus for the distribution to an assembled audience, or to rooms within a building or a group of substantially adjacent buildings commonly owned or operated, of matter re-transmitted from apparatus for one-way wireless telephone reception, or from apparatus for reception in the field covered by paragraph (*b*) of this section 5, or from phonographs, in each case located in the immediate vicinity of such audience or within the building or group of buildings within which such distribution is made.

(*e*) The Telephone Company grants to the General Company non-exclusive licenses in the field of wire telephony, both one-way and two-way, for apparatus and systems for communication only over wires used in connection with apparatus for remote control or actuation of apparatus for power purposes and only in connection

with the operation of apparatus for power purposes, but not for transmission of messages for the public.

(*f*) The Telephone Company grants to the General Company non-exclusive licenses in the field of wire telephony, both one-way and two-way, for apparatus for communication between parts of a train (without regard to the nature of the motive power thereof), or between trains following or approaching each other upon the same system of tracks, or between trains approaching a cross-over or junction point of the systems of tracks upon which they are running, or between trains and signal towers or way-stations within short distances thereof, but in each instance only for use in connection with the operation of such trains but not for train dispatching.

(*g*) Subject to non-exclusive rights reserved for the purposes covered by paragraphs (*c*), (*d*), (*e*) and (*f*) of this section 5, the General Company grants to the Telephone Company exclusive licenses in the field of wire telephony, both one-way and two-way, for all purposes other than for the purposes covered by the paragraphs (*a*) and (*b*) of this section 5; provided, however, (1) that the licenses granted by this paragraph (*g*) for apparatus for reception of programs are licenses only to make and use in connection with a service of transmitting programs by wire telephony over lines other than electric light, electric heat, electric power and electric traction lines, to lease to subscribers to such a service, and to sell only at retail (except as to sales for export) either directly or through the Telephone Company's own direct agents, and said licenses are subject to the condition that the Telephone Company shall retain in itself, or in one or more of its subsidiaries, title to the apparatus and control of its disposition until it is so sold, and (2) that all apparatus made, used, sold, leased or otherwise disposed of by the Telephone Company for distributing to an assembled audience or to rooms within a building or a group of substantially adjacent buildings commonly owned or operated, programs re-transmitted from apparatus for one-way wireless telephone reception or from apparatus in the field covered by paragraph (*b*) of this section 5, in each case located in the immediate vicin-

ity of such audience or within the building or group of buildings within which such distribution is made, shall be treated as if such apparatus were apparatus for one-way wireless telephone reception of programs under the provisions of paragraph (*d*) of subdivision C of section 4 of this article V, and shall be governed by all the provisions of said paragraph (*d*).

6. Power Purposes and Household Devices.

The Telephone Company grants to the General Company exclusive licenses in the fields of (*a*) distance actuation and control by wireless, (*b*) power purposes (including apparatus for distance actuation and control of apparatus for power purposes and apparatus for indicating at remote points the condition or position, of apparatus for power purposes) and (*c*) household devices, in each case for purposes other than communication purposes; provided, however, that in so far as concerns patents for inventions relating to business of the general character which any subsidiary of the Telephone Company now conducts as jobber and any extensions of that business along similar lines (except patents covering articles of the general character which such subsidiary now purchases from the General Company, or its subsidiaries, or sells as agent for the same), the Telephone Company reserves under its own patents (but is granted no license under the patents of the General Company) the non-exclusive right for such subsidiaries to make apparatus embodying the inventions of said patents, or have them made for them, and to sell them in said jobbing business.

7. Railroad Signalling, Radio Goniometry, X-ray Devices.

(*a*) The General Company grants to the Telephone Company non-exclusive licenses in the field of radio goniometry for apparatus for use as part of apparatus in respect of which the Telephone Company is otherwise licensed under this agreement.

(*b*) The General Company grants to the Telephone Company non-exclusive licenses in the field of railway signalling for apparatus incidental to apparatus for train dispatching, for use only by the train dispatcher

or similar official for operating at will, and not automatically, signals, switches, brakes and stops.

(*c*) Subject to non-exclusive rights reserved for the purposes covered by paragraphs (*a*) and (*b*) of this section 7, the Telephone Company grants to the General Company exclusive licenses in the fields of railroad signalling, X-ray apparatus and apparatus associated therewith, and radio goniometry.

8. Train Dispatching.

The General Company grants to the Telephone Company exclusive licenses in the field of train dispatching.

9. Electric Sound Recording.

(*a*) The General Company grants to the Telephone Company exclusive licenses for electrical apparatus for the production of sound records (which records are for the private use of the maker, and not for commercial use or sale) in combination or connection with apparatus in the field of wire telephony other than in connection with apparatus in the field covered by paragraph (*b*) of section 5 of this article V.

(*b*) The Telephone Company grants to the General Company exclusive licenses for electrical apparatus for the production of sound records (which records are for the private use of the maker, and not for commercial use or sale) in combination or connection with apparatus for one-way wireless telephone reception of programs and with apparatus in the field covered by paragraph (*b*) of section 5 of this article V.

(*c*) The Telephone Company grants to the General Company exclusive licenses for electrical apparatus for the production in homes (which records are for the private use of the maker, and not for commercial use or sale) of sound records of entertainment and educational matter, other than apparatus covered by paragraphs (*a*) and (b) of this section 9.

(*d*) Each party grants to the other non-exclusive licenses for electrical apparatus for the production of sound records other than apparatus covered by paragraphs (*a*), (*b*) and (*c*) of this section 9.

(*c*) Nothing in this section 9 contained shall be construed as granting to either party any exclusive license with respect to electrical apparatus for the production of sound records for commercial use or sale, or for the production of master records intended to be used in manufacturing sound records for commercial use or sale.

10. Electrical Phonographs.

(a) The General Company grants to the Telephone Company exclusive licenses for electrical phonographs for use in combination or connection with apparatus in the field of wire telephony other than in combination or connection with apparatus in the field covered by paragraph (*b*) of section 5 of this article V; provided, however, that the licenses granted by this paragraph (*a*) for phonographs for private use in homes for entertainment and educational purposes are licenses only to make and use in connection with a service of transmitting programs by wire telephony over lines other than electric light, electric heat, electric power and electric traction lines, to lease to subscribers to such a service, and to sell only at retail (except as to sales for export) either directly or through the Telephone Company's own direct agents, and said licenses are subject to the condition that the Telephone Company shall retain in itself, or in one or more of its subsidiaries, title to the apparatus and control of its disposition until it is so sold.

(b) The Telephone Company grants to the General Company exclusive licenses for electrical phonographs in combination or connection with apparatus for one-way wireless telephone reception, and in combination or connection with apparatus in the field covered by paragraph (*b*) of section 5 of this article V.

(*c*) The Telephone Company grants to the General Company exclusive licenses for electrical phonographs for private use in homes for all entertainment and educational purposes other than those covered by paragraphs (*a*) and (*b*) of this section 10.

(*d*) Each party grants to the other non-exclusive licenses for electrical phonographs for all purposes other than those covered by paragraphs (*a*), (*b*) and (*c*) of this section 10.

11. Apparatus for Co-ordination of Sound and Pictures.

(a) The rights and licenses of the parties hereto in respect of apparatus for transmitting, receiving, recording or reproducing sound in co-ordination, synchronism or timed relation with the taking, transmission or projection of pictures shall, in so far as the fields of wire and wireless telegraphy and telephony, electrical sound recording and electrical phonographs are involved, be governed by the other provisions of this agreement relating to said fields.

(*b*) In so far as apparatus for the taking or projection of pictures and apparatus for co-ordinating, synchronizing or timing such taking or projection in relation to the recording or reproduction of sound are not covered by the provisions of paragraph (*a*) of this section 11, the Telephone Company grants to the General Company exclusive licenses for such apparatus for private use in homes for entertainment and educational purposes, and each party grants to the other non-exclusive licenses for such apparatus for all other purposes.

12. Submarine Signaling, Scientific and Therapeutic Apparatus, Shop Expedients and Other Applications.

Each party grants to the other, non-exclusive licenses in the following fields:

Submarine signaling.

Scientific apparatus for use of laboratories, colleges and scientific societies, as distinguished from commercial use.

Wireless apparatus for use of professional investigators (as distinguished from amateurs) for experimental purpose only.

Therapeutic apparatus other than X-ray devices and appliances.

Shop tools, appliances, materials and processes, but only for the production of apparatus embodying inventions which the grantee is licensed to make and use hereunder.

All applications, not herein otherwise specified, of inventions pertaining or applicable to or to the use of vacuum tubes, and to generating

(directly or from other currents), modifying, amplifying, transmitting or receiving electro-magnetic waves, variations or impulses for other than power purposes.

ARTICLE VI.

PROVISIONS WITH REFERENCE TO FOREGOING LICENSES.

1. Whenever licenses granted under the terms of this agreement are based upon rights held by the licensor under any agreement requiring the payment of royalties or other deferred payments, measured by the use made of the invention, the party accepting such licenses shall make payments measured by its use of the invention at the same rate and upon the same terms as those agreed to be made by the party originally acquiring the rights.

2. Upon the termination of this agreement under the provisions of article XIV hereof all licenses herein granted shall, during the terms of the several patents, issued or to be issued, in respect of which such licenses exist at the date of termination, continue unaffected and of the same scope and character, whether exclusive or non-exclusive, herein expressed, so far as the grantor thereof has the right to grant such licenses for such terms; and such licenses shall not be limited by the term of this agreement.

3. (*a*) The Telephone Company may grant sub-licenses under its standard form of license contract (a copy of which is now delivered to the General Company) to such operating companies (but not manufacturing companies) as are now or may from time to time be operating under such form of contract. The provisions of this paragraph (*a*) shall apply to any changed form of license contract provided that, as changed, it grants rights in the fields of the General Company no broader than those granted by the present form.

(*b*) Each party hereto may grant to its subsidiaries sub-licenses under the licenses granted to it herein; provided, however, that each subsidiary to which a sub-license shall be granted (excepting, however, sub-licensees pursuant to paragraph (*a*) of this section 3) shall either have entered into an agreement with its parent company effectively subjecting to this agreement all

United States patents then or thereafter during the term of this agreement owned or controlled by it, or have executed to the party hereto other than its parent company an instrument granting to such other party licenses under said patents co-extensive with the licenses herein granted to such other party. Use by any subsidiary of any sub-license granted under this agreement shall for all purposes of this agreement, including determination of royalties payable hereunder, be deemed to be use by its parent company, and ownership, lease or operation of any telephone or telegraph system or station by any subsidiary shall be deemed to be ownership, lease or operation of such system or station by its parent company for all purposes of this agreement.

(*c*) In addition to the sub-licensing provided for in the foregoing paragraphs (*a*) and (*b*), each party hereto may assign or grant sub-licenses under any of the rights granted to it hereunder, provided that in each instance the assent of the other party is first obtained.

(*d*) Each party may, subject to the provisions of section 4 of this article VI, sell or lease to any sub-licensee having a sub-license to use granted under the provisions of any of paragraphs (*a*), (*b*), and (*c*) of this section 3, apparatus for the use of such sub-licensee under such sub-license, notwithstanding that the party granting such sub-license may not be licensed under this agreement generally to sell, lease or otherwise dispose of such apparatus.

(*e*) All sub-licenses granted hereunder shall be subject to all limitations and obligations attaching to the apparatus or system in respect of which sub-licenses are granted, whether under the patents, or under the instruments by which any party acquired the patents or licenses under them; or under this agreement.

(*f*) No disposition by either party of rights hereunder acquired by it, shall relieve such party of any of its obligations under this agreement, or restrict the rights of the parties hereto in operating under or modifying this agreement.

4. Each party agrees that, so far as it is enabled so to do, it will, in disposing of apparatus embodying inventions pertaining or applicable to vacuum tubes, or to

generating, modifying, amplifying, transmitting or receiving electro-magnetic waves, or other apparatus or material the unrestricted sale of which would deprive the other party of rights to which it is entitled hereunder, use such precautions by contracts, leases, restricted licenses or otherwise as may be necessary or advisable in order to prevent its subsidiaries, sub-licensees, customers or others from acquiring (by acquisition of apparatus from it or otherwise) licenses to use the same which the party disposing thereof has no right to grant. In case at any time either party shall claim that apparatus made by the other and capable of use in fields in which the claimant is exclusively licensed under this agreement, has been sold in an amount exceeding the amount reasonably acquired for use in fields in which the maker is licensed under this agreement, the parties shall endeavor by agreement to determine whether there has been such excess sales of apparatus and the amount of the royalties payable thereon as hereinafter provided; and if the parties shall be unable to agree upon any of said matters, the dispute shall be settled by arbitration as hereinafter provided. The party making such claim shall, if it shall prove the fact of excess sales, not be required to prove with the definiteness which would be required in a court of law or equity, the amount of such excess sales, but the arbitrators shall estimate such amount as nearly as they can from such evidence as may be furnished by the parties and the amount so estimated shall be deemed to be the amount of such excess sales. Upon any excess apparatus so determined to have been sold the party making such excess sales shall pay to the other party royalties equal to fifty per cent. of the current retail price during the period during which such excess apparatus was sold.

5. All royalties payable under any provision of this agreement shall continue to be payable to the ends of the terms of the patents in respect of which such royalties are payable, notwithstanding any termination of this agreement.

6. The admission of validity implied in the acceptance of licenses hereunder is limited to the field for which such licenses are granted or agreed to be granted.

7. No licenses under foreign patents are now granted or are to be implied; but except as herein otherwise expressly provided the licenses to make, sell, lease or otherwise dispose of, herein granted under United States patents include the right to make, sell, lease or otherwise dispose of for use abroad in the fields for which such licenses under United States patents are granted, but not for use abroad in other fields. Each party agrees not to export to any country in which the other party has an affiliated company, apparatus purchased from such other party which such other party could not itself so export, in view of existing contract obligations, after notice of such obligations and without first securing a written waiver thereof.

8. Each party represents that in its best judgment it has no outstanding obligations which would prevent it from entering into the agreements and from granting the licenses herein expressed. If, however, it is found that there are such conflicting obligations, the present agreement is made subject to the right to fulfill those obligations.

ARTICLE VII.

INTERFERENCES.

The parties agree to use reasonable endeavors to settle, without litigation, interferences now pending or which may arise involving inventions within the scope of this agreement.

ARTICLE VIII.

ACQUISITION OF PATENT RIGHTS.

Neither party shall acquire from others rights to or under United States patents or inventions, or rights to use secret processes, applicable to the fields of the other party, of such limited character that the other party does not, by the operation of this agreement, receive licenses thereunder of the scope and within the respective fields herein set forth, unless the party proposing to acquire such rights shall first have given the other party an opportunity to be represented in the negotiations and thereby to acquire rights for its field.

ARTICLE IX.

CO-OPERATION AND EXCHANGE OF INFORMATION.

1. Each party agrees that it will, from time to time during the term of this agreement, freely permit the other to have all information in its possession which it may have a right to dispose of with reference to its standardized apparatus or methods or processes applicable to the uses of the other party in fields in which such other party is granted licenses hereunder, but any secret process so disclosed shall be maintained in secrecy by the party to whom it is disclosed. Blue prints, etc., shall be furnished at the cost of preparing the same. For the purpose of acquiring such information each party shall at all reasonable times have access (through a reasonably limited number of accredited representatives who are regular employees under obligation to assign inventions to their employers), to the laboratories, factories and wireless stations of the other, to the end that development work may be expedited and rendered the more effective.

Each party shall, with reference to inventions owned or controlled by it, under which the other party is entitled to rights hereunder and which either party deems to be of sufficient value to justify such action, endeavor to obtain or permit and aid the other to obtain proper patents thereon.

2. Each party shall afford the engineering representatives of the other the fullest possible facilities, consistent with the reasonable operation of the other, for experimenting and for developing and testing apparatus and systems for use in transoceanic telephony, and each shall at all times be given such an opportunity to make such tests, experiments and observations in the transoceanic stations of the other as do not conflict with the service then being rendered by such stations, and each party shall afford to the other such facilities for test, experimentation and observations on ships as it may be able to extend.

3. In the operation of wireless and carrier-current communication, the parties shall co-operate to the end that interference with the operations of either party, due to the operations of the other, shall be minimized, it

being recognized that the available wave lengths are limited.

ARTICLE X.

Purchases as Between Parties.

It is recognized that each party has and will normally continue to have facilities for manufacturing certain apparatus or parts thereof which may be required by the other party under its licenses hereunder, and that a duplication of such facilities may be wasteful and uneconomical. Each party agrees that it will upon request manufacture for and sell and deliver to the other, with reasonable business promptness and within its reasonable manufacturing capacity, on receipt of orders from time to time, and at favorable prices not to exceed those charged to others (except subsidiaries and, in the case of the Telephone Company, Companies of the Bell System) purchasing in like quantities for use in the United States, such apparatus and parts as the former is engaged in manufacturing from time to time and as the latter may desire for use under the licenses granted by this agreement.

ARTICLE XI.

Litigation.

1. Each party shall have the exclusive right to bring suits for infringement in the fields in which its licenses are herein expressed as exclusive, joining as plaintiff in any such suit the patent owner or the party which has acquired from the patent owner the right to sue thereunder.

2. Neither party shall bring suit for infringement of patents against the other party, or against the distributors and jobbing houses owned by or affiliated with either party, because of sales by such party, or by its (or its subsidiaries') distributors or jobbing houses, of apparatus made, in the United States, by others than the parties hereto, it being agreed that the remedy in case of any such infringement shall be only by suit against the manufacturer of those devices; but nothing herein contained shall be construed as the granting of a right to sell infringing apparatus manufactured by others.

8. Each party assigns and transfers to the other all claims and causes of action which it may have against others for infringement in fields in which the licenses herein granted to such assignee are exclusive, together with the right to sue for and collect for its own use all profits and damages arising out of such infringement.

ARTICLE XII.

RELEASES.

Each party reserves to itself the right to deal with the United States Government with reference to settlement for past use of its inventions in telephone and telegraph apparatus and systems. Subject to the foregoing, each party releases the other and the vendees and users of apparatus or systems made by it, from all claims growing out of past infringement of patents, by reason of the manufacture, use and sale of such apparatus and systems by the other party, and its resale or use by such vendees and users.

ARTICLE XIII.

ARBITRATION.

In case any controversy under this agreement (except in respect of interference or priority of rights to inventions or patents) shall arise between the parties to this agreement, which they are unable to adjust between themselves, it shall be settled by arbitration pursuant to the Arbitration Law of the State of New York in the following manner:

Either party may by notice in writing served on the other, appoint one arbitrator and call upon the other to appoint a second arbitrator within thirty days after the receipt of such notice; and each party agrees that upon receiving any such notice it will so appoint an arbitrator. The two arbitrators thus appointed shall, within thirty days after the appointment of the one last appointed, jointly appoint a third arbitrator. The controversy shall be submitted to the three arbitrators in such manner as they shall direct and their decision, or the decision of a majority of them, rendered in writing, shall be final, conclusive and binding upon the parties. In the event that a second arbitrator shall not be ap-

pointed as above provided or the two arbitrators first appointed shall fail to appoint a third, application may be made by either party to the Supreme Court of the State of New York, or to a judge thereof, to designate and appoint an arbitrator or arbitrators, as the case may require, as provided by said Arbitration Law. Each party shall pay its own expenses in connection with the arbitration but the compensation and expenses of the arbitrators shall be borne in such manner as may be specified in their decision in writing.

ARTICLE XIV.

TERMINATION OF AGREEMENT.

This agreement shall continue until July 1, 1933, but shall automatically continue thereafter until cancelled on three years' written notice given after July 1, 1930, by one party to the other party.

ARTICLE XV.

FURTHER ASSURANCES.

The parties agree to execute and deliver such further instruments as may reasonably be necessary for carrying out the provisions and purposes of this agreement.

ARTICLE XVI.

SUCCESSORS.

This agreement is binding upon and shall inure to the benefit of each of the parties hereto and their several successors in business, except that either party may transfer or dispose of any part or parts of its business not involving the grant of any licenses under this agreement, and in such case this agreement shall not be binding upon or inure to the benefit of the successor to that part of the business so transferred.

IN WITNESS WHEREOF, the parties hereto have caused this instrument to be executed on the day and year first above written, by their proper officers thereunto duly authorized.

GENERAL ELECTRIC COMPANY,
By E. W. RICE, JR.
President.

[SEAL]
Attest:
J. W. ELWOOD
Assistant Secretary.

AMERICAN TELEPHONE AND TELEGRAPH COMPANY,
By H. B. THAYER
President.

[SEAL]

Attest:
A. A. MARSTERS
Secretary.

II. The foregoing modifications shall be effective from and after the date of this agreement.

IN WITNESS WHEREOF, the parties hereto have caused this agreement to be executed as of the day and year first above written by their proper officers thereunto duly authorized.

GENERAL ELECTRIC COMPANY,
by OWEN D. YOUNG
Chairman of the Board.

[SEAL OF GENERAL ELECTRIC COMPANY]

Attest:
J. W. LEWIS
Assistant Secretary.

AMERICAN TELEPHONE AND TELEGRAPH COMPANY,
by D. F. HOUSTON
Vice-President.

[SEAL OF AMERICAN TELEPHONE AND TELEGRAPH COMPANY]

Attest:
A. A. MARSTERS
Secretary.

PLAINTIFF'S EXHIBIT No. 215. 313

Oct. 20, 1925. 1,558,437

I. LANGMUIR

ELECTRICAL DISCHARGE APPARATUS

Original Filed Oct. 29, 1913 2 Sheets-Sheet 1

Fig 1

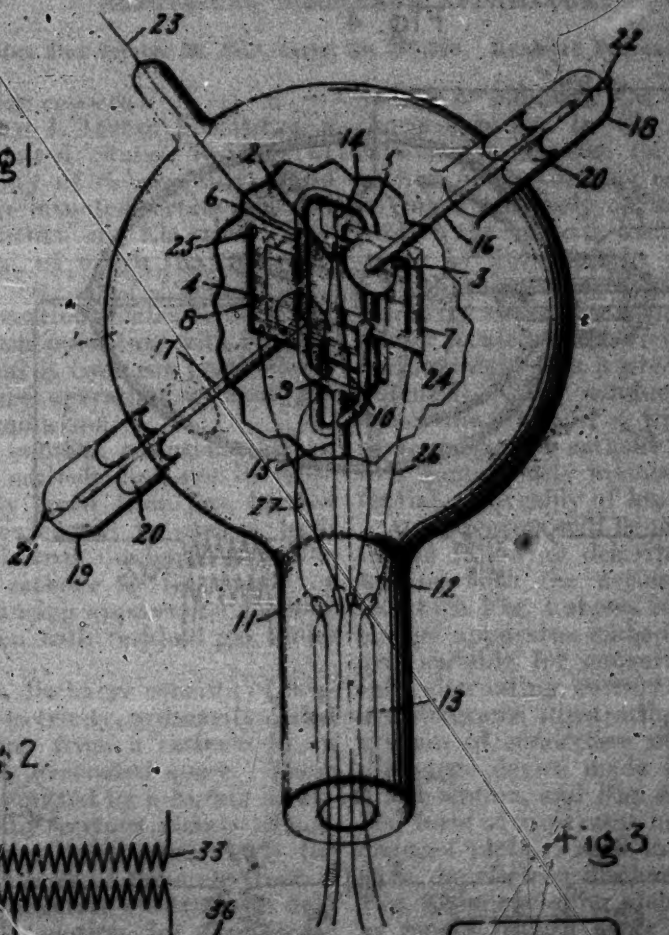


Fig 2.

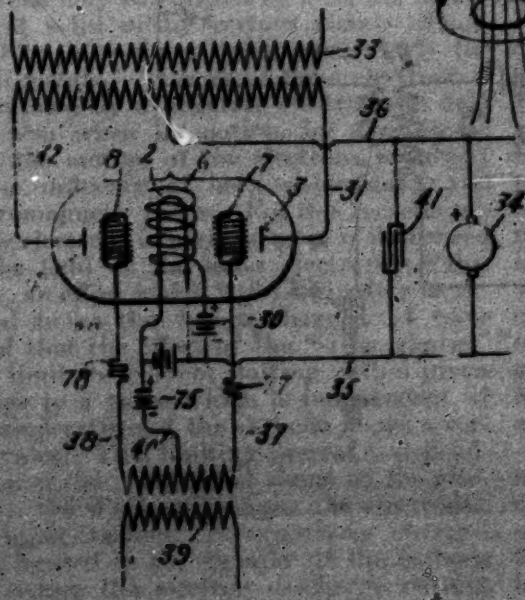
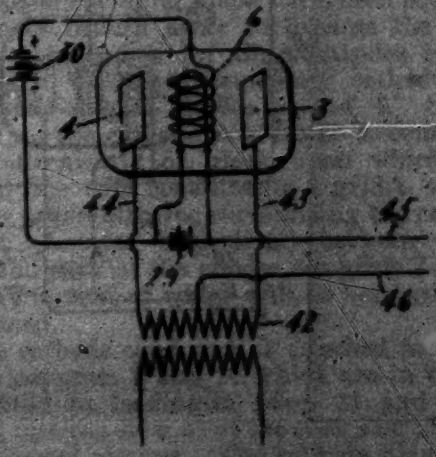


Fig 3



Witnesses:
Chas. B. Stokes
J. Ellis Glen

Inventor:
Irving Langmuir,
by Albert G. Davis
His Attorney

314

Oct. 20, 1925. 1,558,437

I. LANGMUIR

ELECTRICAL DISCHARGE APPARATUS

Original Filed Oct. [illegible], 1913 2 Sheets-Sheet 2

Fig. 4.

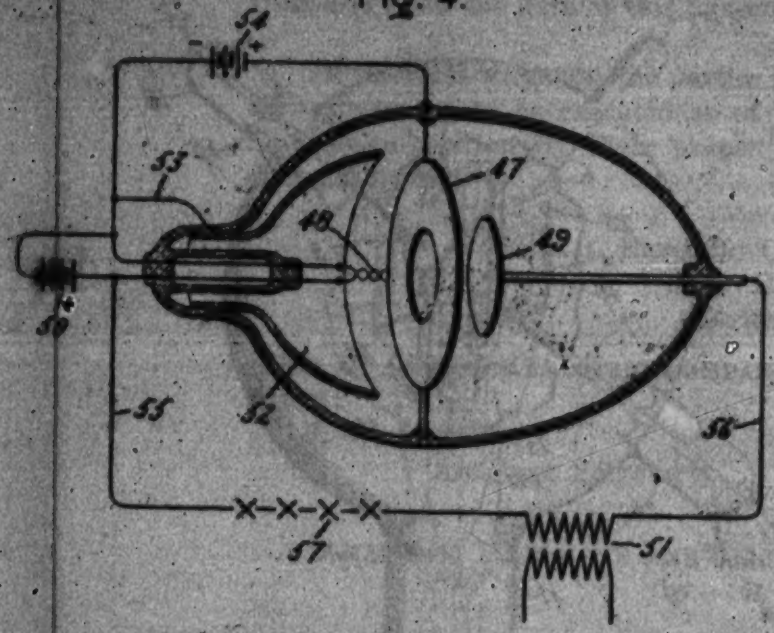
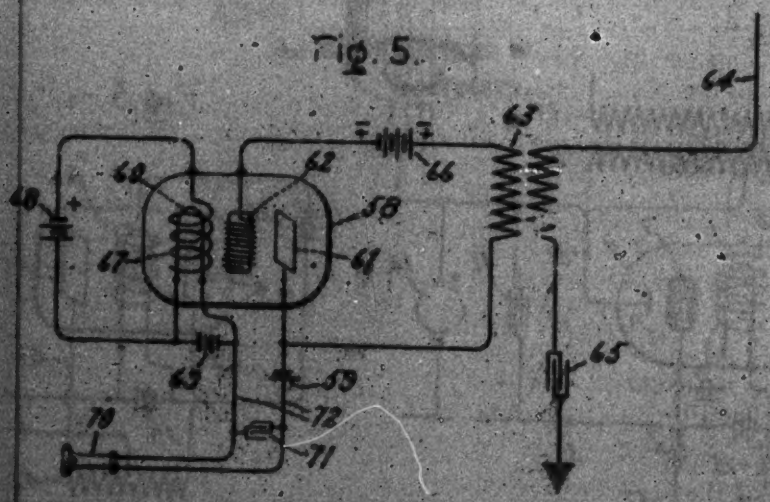


Fig. 5.



Witnesses:

Inventor:
Irving Langmuir,
by Albert G. Davis
His Attorney.

Patented Oct. 20, 1925. 1,558,437

UNITED STATES PATENT OFFICE.

IRVING LANGMUIR, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

ELECTRICAL DISCHARGE APPARATUS.

Application filed October 28, 1913. Serial No. 797,260. Renewed February 20, 1924.

To all whom it may concern:

Be it known that I, IRVING LANGMUIR, a citizen of the United States, residing at Schenectady, county of Schenectady, State of New York, have invented certain new and useful Improvements in Electrical Discharge Apparatus, of which the following is a specification.

The present invention relates to electrical discharge apparatus operating with an electron discharge and it concerns particularly the type of device operating without gas ionization and conduction.

Such a device consists essentially of an electron-emitting cathode, and one or more anodes thoroughly freed from gas, located in an envelope evacuated to such a high degree that an electron discharge can take place from the cathode to the anode or anodes without causing appreciable gas ionization by collision with residual gas molecules.

A pure electron discharge consists of negative charges of electricity, ordinarily called "electrons", moving from a cathode to an anode in a highly evacuated space. These electrons may be emitted by a highly incandescent solid, or by certain metals illuminated by ultraviolet light, particularly the alkali metals. As each of these electrons is surrounded by a negative electrostatic field and, also when in motion, by a magnetic field, the motion of the electrons is subject to the influence of both electrostatic and electromagnetic forces. For this reason each of the electrons in a given space is influenced by the field of the other electrons in this space, an effect which will hereinafter be referred to as the "space charge". I have found that the effect of the "space charge" is to limit the current flowing with a given voltage to a value which is independent of the temperature of the cathode above a certain value. This limiting current is dependent upon the geometrical shape of the electrodes, the distance between the electrodes, and other factors. A negatively charged body located in the vicinity of the cathode will reduce the electron discharge current with a given impressed voltage and may also deflect the electrons dependent upon its position and configuration.

Some of the objects of the present invention are: to reduce the effect of the space charge in an electron discharge device; to modify or eliminate the effect of negatively charged bodies in the proximity of the cathode; to increase the discharge current with a given voltage; to furnish electrons having a relatively uniform velocity and to protect the cathode itself from mechanical injury or distortion by electrostatic forces.

With these objects in view the electron discharge apparatus is provided with a conductor located in the vicinity of the cathode and maintained at a predetermined positive potential. This conductor ordinarily assumes the form of a wire grid or grating surrounding the cathode and it is connected to a continuously maintained source of potential, preferably of low voltage.

My invention will be more fully explained in the following description taken in connection with the accompanying drawings in which Fig. 1 shows in perspective a discharge apparatus embodying my invention and suitable for converting direct current into alternating current; Figs. 2, 3 and 5 are diagrams illustrating various electrical systems of connection utilizing an electron discharge device made in accordance with my invention, and Fig. 4 illustrates a modified form of apparatus in which a positively charged plate is used instead of a grid.

In the electron discharge device shown in Fig. 1, the enclosing globe 1 has been shown as partly broken away to disclose the interior arrangement of the electrodes comprising a V-shaped filamentary cathode 2, and plate-shaped anodes 3 and 4. Surrounding the cathode is a frame 5, consisting conveniently of glass, upon which is wound fine wire constituting a grid 6 with closely adjacent turns surrounding the cathode 2. Located respectively between this grid and each of the anodes are grids 7 and 8, the function of which will be hereinafter explained.

The cathode conductor is attached to terminal supports 9 and 10 which are in turn connected to leading-in wires 11 and 12, sealed into the stem 13 of the enclosing globe in the usual manner. The cathode filament is maintained taut by being anchored by its lig[illegible] by means of the spring 14 attached to the frame 5. The electrodes and grid wires consists preferably of ductile tungsten. The cathode and grids are all carried by glass stems attached to a pedestal 15. The anode stems 16 and 17 consist of tung-

sten or molybdenum and are held in position in the extensions 18 and 19 of the bulb by springs 20, which grip the walls of the bulb. Connection is made to the anodes in the usual manner by the leading-in wires 21 and 22. Connection to the grid surrounding the cathode is made by a leading-in wire 23. The grids 7 and 8 are preferably wound upon metallic frames 24 and 25 consisting, for example, of ferro-chrome which thus short-circuit the turns of the gird. Electrical connection is made thereto by conductors 26 and 27. The relative position of the anodes the cathode and the grids is more clearly indicated in a diagrammatic manner in Fig. 2. Fig. 1 illustrates particularly the structural features.

As shown in Figs. 2 and 3, the cathode 2 is maintained at incandescence by means of a battery 29, or other suitable externally located source of energy. The surrounding grid 6 is attached to the positive terminal of a source of potential, for example a battery 30, the negative terminal of which is connected to the cathode.

The discharge device is evacuated to the highest obtainable vacuum, the electrodes being freed from gas by operating the device while on the pump at a voltage below the value at which harmful gas ionization, as indicated by blue glow, takes place. As gas is driven out of the anode by electron bombardment, the impressed voltage is progressively increased, the removal of gas by the pump being continued. The impressed voltage thus attained before sealing-off should ordinarily be higher than the voltage at which the device is intended to operate. The degree of vacuum in the completed device while depending somewhat upon the character of the device should ordinarily be as low as a few hundred thousandths of a millimeter of mercury, preferably even lower.

The system shown in Fig. 2 is adapted particularly for the conversion of direct current into alternating current and for this purpose the anodes 3 and 4 are connected by means of conductors 31, 32 to the primary winding of a transformer 33. Energy is supplied by a direct current source of energy 34, for example, a dynamo, or a battery connected at its negative terminal by means of conductor 35 to the cathode and at its positive terminal by means of conductor 36 to an intermediate point upon the primary of the transformer 33. The grids 7 and 8 are connected by means of the conductors 37 and 38, to a source of alternating current 39 having the frequency desired for the alternating current to be produced by the device. This source has been diagrammatically indicated as a transformer altho of course any suitable alternating current source may be used. The cathode 2 is connected by means of a conductor 40 to an intermediate point on the secondary of the transformer 39.

The operation of the system above described is as follows:—When the cathode 2 is brought to incandescence it emits electrons, which travel under the influence of the impressed electromotive force to a positive electrode. When, however, a conductor, located between the cathode and an anode between which electrons are passing, is negatively electrified, the electrons are repelled in accordance with the degree of negative charge, thereby decreasing or interrupting entirely the discharge current. On the other hand, when a conductor, located between an electron-emitting cathode and an anode, is positively electrified the discharge is assisted and the current increased. Some of the electrons go to the positively charged conductor, but when this conductor has a relatively small obstructing surface, as in the case when a fine filament serves as the grid or other conducting body, very little energy will be absorbed thereby. For example, a tungsten wire having a diameter of about .0004 to .0010 of one inch wound with about 100 turns to the inch may be used but the turns per inch vary widely. When the impressed electromotive force between cathode and anode is high the amount of energy lost by the absorption of electrons by a grid having a relatively low positive charge is negligible.

As the grids 7 and 8 are made alternately negative and positive by the alternating source 39, the discharge current, or stream of negative charges, passes in turn to anodes 3 and 4, thereby setting up an alternating current in the primary of the transformer 33, and in that manner repeating in the divided output circuit, acting as the primary of the transformer, with amplified energy the electric waves in the divided input circuit, acting as the secondary of the transformer 39. If desired, a condenser 41 may be provided in order to absorb current variations and to neutralize the inductive effect of the transformer and provide a more rapid rise and fall of current. At any given instant either of input electrodes 7 or 8 will be negatively charged, and being in close proximity to the cathode, will tend to reduce the electron current flowing. However, when a positive field is established in the vicinity of the filament by the grid 6, this grid screens the cathode from the negative field, and assists the flow of electron current, thus making possible the combination of two repeating elements in a single electron discharge apparatus. The electrons are emitted by the cathode at variable speed but all being subject to the same static field which greatly increases the speed of all an equal amount, the differences of speed rep-

resent a relatively small fraction of the impressed resultant speed. As the positive field near the cathode opposes the current-reducing effect of the space charge, the distance between the cathode and the anodes may be increased without sacrifice of efficiency.

Some energy is lost by the absorption of the electrons by the positively charged grid 6 but as its surface is small and the positive potential may be made relatively small as compared with the voltage impressed between the cathode and the anodes, this loss will form but a relatively small proportion of the total amount of energy in the output circuit.

It is desirable that the rise of static potential of the grid becoming negative, should be rapid so as to shut off the flow of electron current completely to its corresponding anode. This result can be effected by making the alternating source 39 of high potential but this also increases the positive charge on the companion grid. A high positive grid potential increases the absorption of energy by the grid. By including a battery 75 or other source of potential in the conductor 40 connected to the cathode and an intermediate point of the secondary of the transformer 39, with its negative terminal connected to the transformer, the potential on the grid negatively charged is increased, and the potential on the grid positively charged is diminished, providing, of course, that the potential of the source 75 does not exceed the potential of the source 39. If desired resistances 77, 78, may be included in the grid circuits 37, 38, or these resistances may be replaced by a single resistance in conductor 40 to reduce current flow therein without reducing the potential. In some cases such resistances may make a separate superimposed negative potential unnecessary.

In the system illustrated by Fig. 3, an electron discharge tube is employed to rectify alternating current furnished by the primary of a transformer 42, the terminals of which are connected to the anodes 3 and 4, respectively, by conductors 43 and 44. The conductor 45 of the direct current consumption circuit is connected to the cathode 2 and the conductor 46 of the direct current circuit is connected to a point of intermediate potential upon the secondary of the transformer 42. It will be observed that the electrodes 3 and 4 will be in turn made positive and negative, current passing from the cathode to the positive electrode. Here likewise the electrode which is connected to the opposite terminal of the source, and hence is negative, would act to cut down the current passing from the cathode to the positive electrode. This effect, however, is prevented by the positively charged grid 6.

In the case of a rectifier having a plurality of electrodes functionating as anodes, the current-reducing effect of the electrodes when negatively charged is especially marked as the drop of potential in the direct current load will reduce the potential of the positive electrode which is taking current. As no current is flowing to a negative electrode, it will have the full potential of the source. For this reason also the mechanical distortion of the cathode located in the unsymmetrical field would be serious were the positive grid 6 not present, whereby the cathode is screened and protected.

The positively charged body need not necessarily be grid-shaped. Fig. 4 illustrates somewhat diagrammatically a rectifying device in which a plate 47 is located between an electron-emitting cathode 48 and an anode 49. Heating current is supplied the cathode conductor by a battery 50, and a source of energy for example, a transformer 51 is connected between the cathode and the anode. Surrounding the cathode is a concave dished plate 52, which is maintained negatively charged, conveniently by connecting it to the cathode by means of a conductor 53. This ring serves to modify the static field so as to focus the electrons into a fairly well-defined stream which passes through an aperture in the plate 47 to the anode.

By maintaining the plate 47 positively charged, for example, by means of a battery 54, the passage of the electrons from the cathode to the anode is assisted. The potential of the battery 54 and hence the charge on the plate 47, may be only a fraction of the potential between supply conductors 55, 56. The electrons will be attracted to the plate 47 but will largely pass through the aperture in the same as this represents the center of static attraction. By making the potential of the plate 47 relatively low the loss of energy by the absorption of electrons on the part of the plate 47 will be relatively small, and will be more than compensated by the increase in discharge current. The rectified current may be utilized by load devices 57. If it is desired to utilize both half waves of the alternating current, two sets of the devices illustrated are used in any well-known manner, such, for example, as that disclosed in Arsem Patent #920,371, or Alexanderson Patent #998,445.

As indicated in Fig. 5 the positively charged conductor may be used to advantage in a device for amplifying or repeating weak variable currents, such as signals in radio-telegraphy, or telephony. The repeater or electron discharge tube 58 is provided with a local source of energy, for example a battery 59, which may be of very low voltage, and is connected between the

cathode 60 and the anode 61. The grid 62 and the cathode 60 are connected to the secondary of a transformer 63, the primary of which is included in the antenna circuit. The latter has as usual an aerial antenna 64, and a grounded condenser 65. The grid 62 may be maintained at a definite potential by a battery 66. The cathode is surrounded by a grid 67, maintained at a perdetermined positive potential with respect to the cathode by a battery 68. When the cathode is heated by a local source of energy 69, a current will tend to flow from the cathode to the anode but this current is either prevented from flowing or is greatly reduced when the field of the grid 62 is negative. As the electrons are drawn away from the cathode 60 by the positive field furnished by the grid 67, a very low voltage may be used in the plate circuit, in fact, I prefer in some cases to use but a single cell for the battery 50, as indicated. A negative potential on the grid 62 on the other hand may be made relatively high. The current variations in the electrode circuit 72 due to the signal impulses impressed upon the grid circuit, are correspondingly great. The signals may be received by a telephone 70, or other suitable receiver, connected in shunt with a condenser 71.

The sensitiveness of this arrangement is especially marked as the electrons leave the grid 67 at substantially uniform velocity and hence are all affected to an equal extent by the variations in the negative charge of the grid 62.

What I claim as new and desire to secure by Letters Patent of the United States is:—

1. A discharge apparatus operating with an electron discharge comprising a highly evacuated envelope, an electron-emitting cathode, an anode, a conductor therein located near the cathode, means for maintaining said conductor at a substantially uniform positive potential with respect to said cathode, and separate means within said envelope for varying the electron discharge between said cathode and anode.

2. An electrical discharge apparatus, comprising an electron-emitting cathode, an anode, an envelope therefor, said electrodes and the space in said envelope being freed from gas to a degree permitting a substantially pure electron-discharge to take place therein without gas ionization, a conducting body in said envelope located near the cathode, and a source of potential having its positive terminal connected to said body and its negative terminal directly to the cathode.

3. An electron discharge device comprising a highly evacuated container, a cathode adapted to be heated to incandescence independently of the operating current of the device, an anode, a conductor located in part at least between said cathode and anode, means for maintaining said conductor at a uniform positive potential with respect to the cathode, and independent means for establishing an electrostatic field to control an electron discharge between cathode and anode.

4. An electrical discharge apparatus comprising an evacuated container, an electron-emitting cathode, a cooperating anode and a conductor in part surrounding the cathode, means for maintaining said conductor at a uniform positive polarity with respect to the cathode, and means for producing a negative charge in the vicinity of said cathode.

5. The combination of an electron discharge device comprising an evacuated container, an electron-emitting cathode, an anode, a conductor coiled about said cathode but spaced apart therefrom, and a source of potential having its positive terminal connected to the said conductor and its negative terminal connected directly to the cathode.

6. The combination of an electron-discharge apparatus comprising a cathode, means for heating said cathode, cooperating anodes located on opposite sides of said cathode, a grid surrounding the cathode but spaced apart therefrom, a source of potential having its positive terminal connected to said grid, grids located respectively between said surrounding grid and the anodes, and a source of alternating potential connected to said intermediate grids.

7. The combination of a discharge device, comprising an envelope, an electron-emitting cathode and an anode, a conductor located near said cathode, means for maintaining said conductor at a positive potential with respect to said cathode, a second conductor located near said cathode, and means for maintaining said second conductor at a negative potential with respect to said cathode.

8. The combination of an enclosing envelope, an incandescent cathode, a plurality of anodes, a charge-controlling conductor surrounding said cathode in part at least, a source of potential having a positive terminal connected to said conductor and a negative terminal connected to the cathode, a transformer, connections between the terminals of said transformer and said anodes, a source of unidirectional current connected between said cathode and an intermediate point on said transformer primary, charge-controlling conductors located between said cathode and said anode, and means for charging said conductors alternately negative and positive.

9. The combination of an enclosing envelope, an incandescent cathode, a plurality of anodes, a charge-controlling conductor

surrounding said cathode in part at least, a source of potential having a positive terminal connected to said conductor and a negative terminal connected to the cathode, a transformer, connections between the terminals of said transformer and said anodes, a source of unidirectional current connected between said cathode and an intermediate point on said tranformer primary, charge-controlling conductors located between said cathode and said anodes, a source of alternating current connected to said charge-controlling conductors and a source of direct current connected at the positive terminal to said cathode and at the negative terminal to a point of intermediate potential on said alternating current source.

10. The combination with an electron discharge device comprising a cathode and a pair of input electrodes enclosed in an evacuated envelope, a transformer secondary having its terminals connected to said input electrodes, a source of direct current having its positive terminal connected to said cathode and its negative terminal connected to an intermediate point in said transformer secondary, and means for impressing an alternating potential upon said transformer secondary.

11. The combination with an electron discharge device comprising a cathode provided with means for heating it to incandescence and a pair of input electrodes enclosed in an evacuated envelope of a transformer secondary having its terminals connected to said input electrodes, a source of direct current having one terminal connected to said cathode and its other terminal connected to an intermediate point in said transformer secondary, and means for impressing an alternating potential upon said transformer secondary.

12. The combination with an electron discharge device comprising a cathode provided with means for heating it to incandescence, a pair of anodes and a pair of input electrodes enclosed in an evacuated receptacle, said input electrodes being located between said cathode and said anodes, means for maintaining both of said input electrodes normally at a definite potential with respect to said cathode which is different than that of the cathode, and means for charging said input electrodes alternately negative and positive.

13. An electron-discharge device comprising an evacuated vessel containing a cathode adapted to be heated to incandescence independently of the operating current of the device, an anode, a discharge controlling electrode and a fourth electrode near said cathode, means for producing a current between said cathode and said anode, and means for maintaining said fourth electrode at a definite potential with respect to said cathode.

14. A device of the audion type comprising a thermionic cathode, an anode and an auxiliary electrode, means for supporting said auxiliary electrode, said cathode being filamentary in form, and a planary supporting frame therefor parallel to one of said electrodes and comprising spaced parallel members.

15. Parallel supporting members, and a filamentary thermionic cathode insulatingly supported at a plurality of points thereby, a grid frame at each side of said cathode, and an arbor for supporting said members and said frames.

16. A device of the audion type comprising parallel grids, a support therebetween comprising spaced parallel members, and a cathode extending between said members and supported thereby.

17. The combination in an electron discharge device of an evacuated receptacle containing an electron emitting cathode, an anode and two grids interposed between cathode and anode, means for maintaining the grid nearest the cathode at a constant positive potential with respect to the cathode, and means for varying the potential of the grid nearest the anode with respect to the cathode.

18. The combination in an electron discharge device of an evacuated receptacle containing an electron emitting cathode, an anode and two grids interposed between cathode and anode, means for maintaining the grid nearest the cathode at a positive potential with respect to the cathode, means for maintaining the grid nearest the anode at a negative potential with respect to the cathode, and means for varying the potential of the grid nearest the anode with respect to the cathode.

19. The combination of an electron discharge device comprising an electron emitting cathode, an anode, and two grids interposed between cathode and anode, means for maintaining the grid nearest the cathode at a constant positive potential with respect to the cathode, means for varying the potential of the grid nearest the anode with respect to the cathode, and means for impressing upon the anode a positive potential of greater value than that impressed upon the grid nearest the cathode.

20. The combination of an electron discharge device comprising an electron emitting cathode, an anode and two grids interposed between cathode and anode, means for maintaining one of said grids at a constant positive potential with respect to the cathode, and means for varying the potential of the other grid with respect to the cathode.

21. The combination of an electron dis-

charge device comprising an electron emitting cathode, an anode and two grids interposed between cathode and anode, means for maintaining one of said grids at a constant positive potential with respect to the cathode, means for varying the potential of the other grid with respect to the cathode, and means for impressing upon the anode a positive potential of greater value than that at which the first of said grids is maintained.

22. An evacuated vessel containing a filament electrode and a cold electrode, a second cold electrode located between the filament and the first cold electrode, and a third cold electrode located between the filament and second cold electrode.

23. An evacuated vessel containing a filament electrode and a plate electrode, a grid electrode interposed between the filament and the plate electrode, and a second grid electrode interposed between the first grid electrode and the filament.

24. An electron discharge device comprising an evacuated vessel containing an electron emitting cathode, a grid electrode surrounding said cathode and a second grid electrode outside of said first grid electrode, a stem through which leading-in conductors for at least two of said electrodes are sealed, and a support for all of said electrodes arising from said stem.

25. An electron discharge device comprising an evacuated vessel, an electron emitting cathode, a grid electrode, a second grid electrode interposed between said cathode and the first grid electrode, a stem through which leading-in conductors for a plurality of said electrodes are sealed, and a support for all of said electrodes arising from said stem.

26. An electron discharge device comprising an evacuated vessel, an electron emitting cathode, a grid electrode, a second grid electrode interposed between said cathode and the first grid electrode, and a support of insulating material within said vessel for supporting all of said electrodes.

27. An electron discharge device comprising an electron emitting cathode, an anode, a pair of grid electrodes located in different planes between said cathode and said anode, an evacuated vessel, and a support of insulating material for supporting the cathode and grid electrodes in desired spaced relation within said vessel.

28. In an electron discharge device in which a stream of electrons passes from one point to another, a plurality of grids located in different planes and successively passed by the electron stream.

29. In an electron discharge device in which a stream of electrons passes from one point to another, a plurality of grids which are successively passed by the electron stream.

30. An electron discharge device comprising an electron emitting cathode, a grid electrode, a second grid electrode interposed between said cathode and the first grid electrode, an evacuated container, and supporting means for supporting all of said electrodes from a single point in said container.

31. An electron discharge device comprising an electron emitting cathode, a grid electrode, a second grid electrode interposed between said cathode and the first grid electrode, an evacuated container and supporting means for supporting all of said electrodes from a single point in said container, said supporting means being arranged to insulate all of said electrodes from one another.

32. An electron discharge device comprising an evacuated vessel containing an electron emitting cathode, a grid electrode, a second grid electrode interposed between said cathode and the first grid electrode, a stem through which leading-in conductors for a plurality of said electrodes are sealed, and means for supporting a plurality of said electrodes from said stem.

33. An electron discharge device comprising an evacuated vessel containing an electron emitting cathode, a grid electrode, a second grid electrode interposed between said cathode and the first grid electrode, a stem through which leading-in conductors for a plurality of said electrodes are sealed, and means for supporting all of said electrodes from said stem.

In witness whereof, I have hereunto set my hand this 27th day of October 1913.

IRVING LANGMUIR.

PLAINTIFF'S EXHIBIT No. 216.

Nicolson Note Book.

(Not printed in full.)

PLAINTIFF'S EXHIBIT No. 216-A.
Certain Pages of Nicolson Note Book.

55

N4

Test 2a.

Relative deflections at 42 Volts (Saturation)

Filament No 1	to	Grid 1/4" (+) #2	1260
— —	to	Fil. No 3 (broken)	0
	to	Fil. No 2 (cool)	500
	to	Grid No 3 (1/2")	1320
	to	plate Anode	1300
	to	Fila. No 2. (incand)	1000

but this is due to say 10 volts in incandescent circuit

	to	Fil No 2 (cool) +10 V (B) = say	900

∴ incandescent no advantage

"N 4"

Test 3

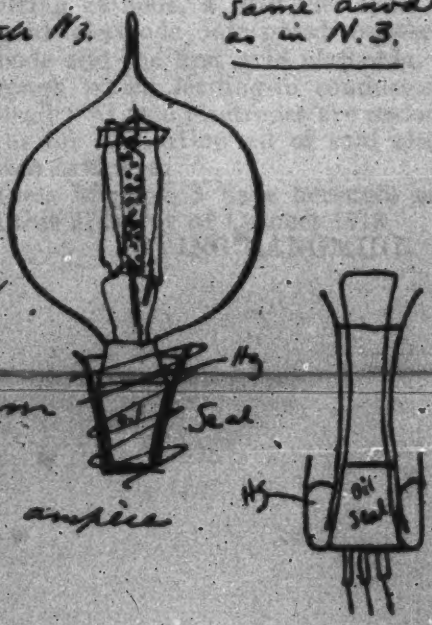
Using both filaments with varying anodes (Grid).—
Grid No 3 (½") gave a greater deflection than to anode
(Fil filament No 1 broke several times — after leaving its support)

N5

Same as tube N3.

Same anode as in N.3.

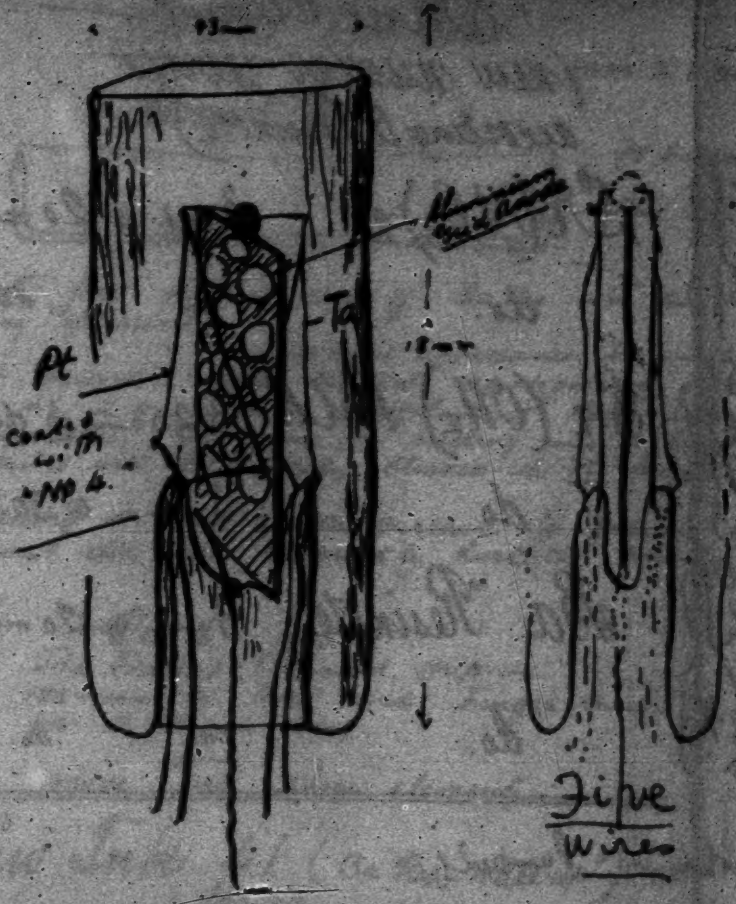
Platinum Strip Filaments (Two)
65 mm. × 0·3 mm. × 0·05 mm
covered with The
CaO Cream #4 (2)
as made by Mr. Hull.
evacuated to highest vacuum
by Molecular pump at
9 a.m. flashed to 2·35 ampère



May 7th 1913

N6.

Comparison of Ta. & Pt. coated with #4 Filaments



Dimensions

Anode (perforated) Aluminum - 62 — X 30 — X .8 —
- 3mm perforations ca. 0.9 cm diameter.

Cathodes Ta . . . 10.3 80 — X —

Pt (pairs) . . . 1.04 .88 — X 0.3 — X 0.05 —

Distance betw: do: Minimum from Grid (anode) Ta: 2 mm
Pt: 1.5 mm

Vacuum: Molecular Pump. Highly evacuated

* Nehnelt coating: No. 4. is a creamy paste of CaO

Flashing { Pt: 1.5 amp ; run at 15-19 Volt;
Ta: 30 Volt ; " " H_2 - 2-4 Amp.

See Page 65

121 Aug. 5. 1913

New Tubes

— Three Element —
(new number series according to Trimble)

Mr. Trimble. Flashed @

N26	$Sr(NO_3)_2$	3 amps @ 20 min	2 amps in Medium Vacuum
N27	do.	do. do.	
N28	$Sr(OH_2)$ + KOH	3.25 amps @ do.	
N29	do.	3 amps @ 30 min	
N30	Ba Resinate	3 amps @ 20 min	
N31	do.	do. do.	

#31 Broke in Pumping.

(Note Plain numbers are Mr. Trimble's)

N26 (#19)	Ba Res.	3 Amps · 20 min.
N30 (#22)	Ba Res	(see p. 129)
N31 (#23)	$Sr(NO_3)_2$	developed as resis tance on Evacuat.

(some of NO_3 got into Pt joint)

see Note page 135

October 4th 1913
Commencement of Construction of Filament 1 to 8 = 136 to 143

Manufacture of 15" Length Pt. Coated Ba Res. Filament

0.3 mm X 0.05 mm

Length "A"

Covered with fine aqueous coat of Ba Re in the baking and cooling operations.

Filament appearance is uniformly black and smooth; after a total operation of about one hour at 2.0 amperes the filament was placed in a dessicator, put away for cutting into 4 lengths, sealed with HCl, duly cleaned etc Pt. bright.

Turning on and off the current in filament several times did not apparently hurt the coating.

Oct 6. 1913
The Finished Filament Strip:—
Exposed 100 mm to Air and Finger tested for 2 hours (ca)
and
made into three element:—

* New Tube 41 (Ba Res - "made up") 3 elements (Bk. 36 1 & 2)

Burned or Flashing @ 1.9 amps

* New Tube 42 (Pt. & covered with KOH) T
and heated to 2 amps for 5 minutes. see page 327

T (KOH, because the clamping ends have to clean off Oxide by HCl acid and alkali is required to remove them, it is then thoroughly washed & dried in blotting paper; washed again).

* New Tube A 38 (straight from Dessicator) —
and heated at 2 amps in air for 5 minutes
3 Elements

(Bk 36 56)

Above Lamps "flashed" in vacuo at 1.9 amps

139

9 ~~August~~ October 1913

Exp. 4.

Nickel Filament

Made-up Length (F) 15° Coat 9:- { Ni-BaRe well Coated

2.5 Amps for ½ hour.

[New Filaments C, D, F see page 138]

New Tubes & Filaments C, D, F

Bk 20 #43	Pt	Sr(OH)₂	(Length C)	with ~~#42~~ see p. 137	1.5 Amp. for 20 min. on Molecular Pump
# 44 (Bk 20. 195)		do	do		
# 45 (Letter)		do	do		1.75 amps for 20 minutes
# 46 (B)		do	do		See Book 36 - P 62 64
# 47 (D)		do	do		
# 48	Pt	BaRes / Ba(NO₃)₂	Length (D)		ditto amps See Book 36 - Page 60 (weld spot)
~~# 49~~		do	do		do (Begin point in Filament) do do
~~# 50~~		do	do		
# 51	See Book 36 P 61	do	do		Bk 36 p 61. Heated up to 1.7 amps Flash not used / Broke 24. (Flash)
~~# 52~~		do	do		
# 53	Ni - BaRes.		(D)		1.7 amps & sealed off without Flash.

Bk 36 p 61

11 Oct 1913

140

New Tubes & Filaments

E.G. Starke @ 1.75 amps for

#54 Pt-Ba ~~(NO3)2~~ Res Bk 36 p. 67

#55 " do Bk 36 p. 67 } + KOH Length (E.)

#56 Burned out Oct. 21/13 WHT do Bk 36 p. 66 } do

#57 Bk 36 p. 66 Pt-$Ba(NO_3)_2$ Fresh Ba(NO3)2 1.5 Amp @ 60 Volts no B.H. Tube Res P. did no good.

#~~58~~ do

#~~59~~ do } Length (G)

Burned out at 1.8 Amp No B.H. with #65

Exp V

Length (H) 1, 2, 3,

Saturday - Monday

Pt-Ba Res (H1) 70 mm dipped in HCl, washed in KOH & H_2O

(H2) 70 " Left in KOH (#60) ←

(H3) 70 " Left in H_2O → (#61)

Bk Oct.

(H_2) was at apparently appeared

(H_3) " " " " but H_2O contained a whitish sediment

#60 Pt-Ba Res Washed off with HCl (see H1) } 0.9 Amps

Bk 36 p. 66

#~~61~~ do after 48 hours in H_2O (see H3) ("damaged filament") @ 1.75 amp } Length H

#~~62~~ do untouched

#63 Pt. Bases for Pierce (with #48) Tube } on Pump on Sauda on 100 Volts @ 1.75 } Blue Haze Gauge out ~~15~~ 20 min.

Bk 20 p. 197 Retubulated & evacuated at with Gaede & Liquid Air

328

PLAINTIFF'S EXHIBIT No. 217.

L. DE FOREST.

OSCILLATION GENERATOR.

APPLICATION FILED DEC. 28, 1915.

1,201,273. Patented Oct. 17, 1916.

Fig. 1.

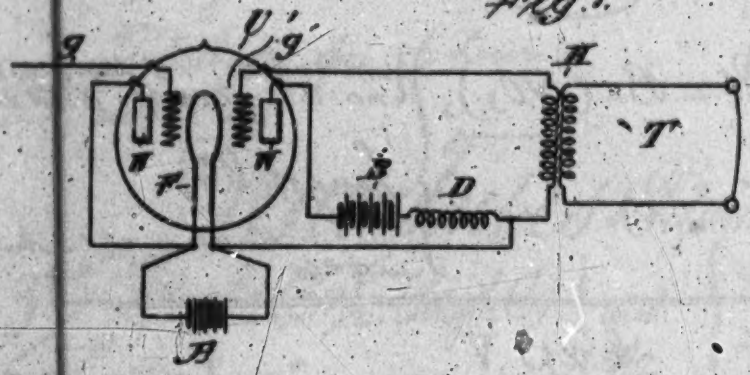
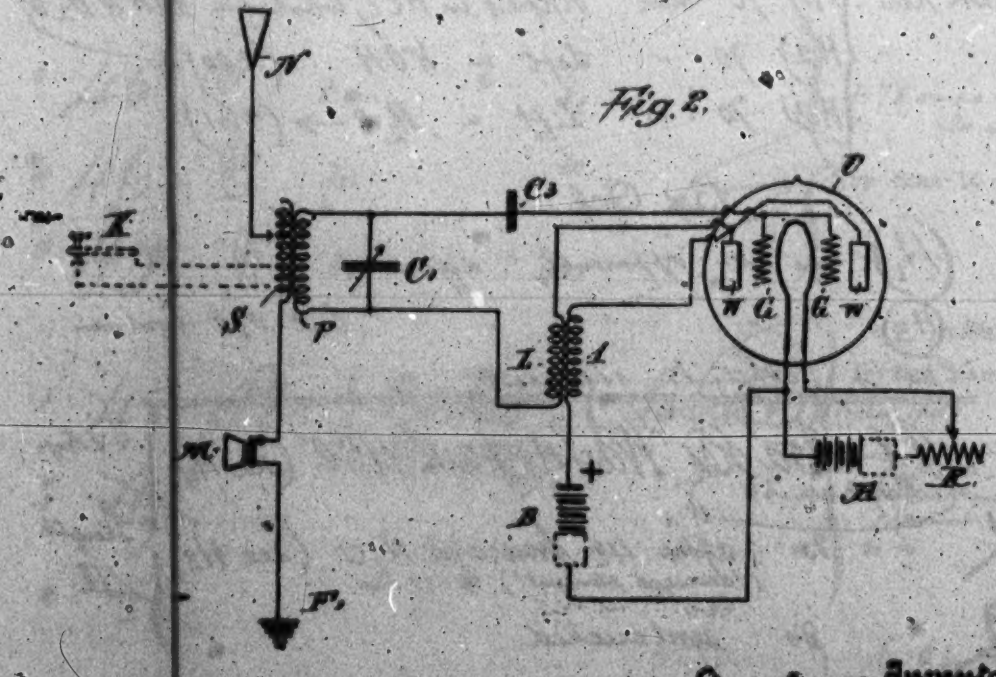


Fig. 2.



Inventor
Lee de Forest
By his Attorney
Samuel F. Darby

UNITED STATES PATENT OFFICE.

LEE DE FOREST, OF NEW YORK, N. Y., ASSIGNOR TO DE FOREST RADIO TELEPHONE AND TELEGRAPH COMPANY, OF NEW YORK, N. Y., A CORPORATION OF DELAWARE.

OSCILLATION-GENERATOR.

1,201,873. Specification of Letters Patent. Patented Oct. 17, 1916.

Original application filed May 13, 1915, Serial No. 27,771. Divided and this application filed December 30, 1915. Serial No. 69,987.

To all whom it may concern:

Be it known that I, LEE DE FOREST, a citizen of the United States, residing at New York city, county of Bronx, State of New York, have made a certain new and useful Invention in Oscillation-Generators, of which the following is a specification.

This invention relates to generators of oscillating, or pulsating currents and embodies subject matter divided from my application Serial No. 27,771, filed May 13, 1915.

The object of the invention is to provide a generator of oscillating, alternating or pulsating electric currents which is simple and efficient.

A further object is to provide an oscillation generator of the character referred to capable of generating oscillating, alternating or pulsating electric currents of substantially uniform amplitude.

Other objects of the invention will appear more fully hereinafter.

The invention consists substantially in the construction, combination, location and relative arrangement of parts, all as will be more fully hereinafter set forth, as shown in the accompanying drawing and finally pointed out in the appended claims.

Referring to the drawing: Figure 1 is a circuit diagram showing an arrangement of generator of continuous, oscillating, alternating or pulsating currents embodying my invention. Fig. 2 is a similar view showing a modified arrangement of oscillating generator embodying my invention as applied for use in connection with radio systems.

In carrying out my invention I employ a closed and preferably, evacuated vessel or bulb in which are located cold and hot electrodes, and I provide suitable circuit connections and current supply source to said electrodes, and where the generator is employed in connection with radio systems I associate the generator with a suitable radiating system having means connected thereto or associated therewith for altering or modifying the radiations from the system either manually, as through a telegraph key, or otherwise, as for instance, a telephone transmitter, in accordance with signal code or sound waves.

Referring to Fig. 1, U designates the evacuated vessel or bulb. Located within this vessel or bulb is a hot electrode F, which, in the form shown, is a filament and also located within the evacuated vessel U are the cold electrodes g and W. To the filament or glower electrode F current is supplied from any convenient source as indicated at A, which source may be a battery or a direct current generator. Where an alternating current generator is employed the frequency thereof for wireless telephone operation, should be above that of the essential frequencies of voice sounds, say for instance, fifteen hundred cycles per second, or higher. For wireless telegraph work the frequency of the generator may be very much lower, say, for example, five hundred cycles per second.

In the particular form shown but to which my invention is not to be limited or restricted, I employ two cold electrodes W in the form of plates or wings, and one cold electrode g in the form of a grid and I have shown the grid electrode g positioned between the hot electrode F and one of the cold plate or wing elements W. A circuit has one of its terminals connected to the cold grid electrode W. This connection including a source of current B to an inductance coil D. This circuit connection of electrodes g and W is also connected to one side or terminal of hot electrode F. The other cold plate or wing electrode W is shown connected to the other side or terminal of the hot electrode F. If desired, the circuit connection between the cold electrodes g and W may be suitably associated with a telephone indicated at T. This association may be accomplished through a transformer H or other suitable form of coupling.

Referring to Fig. 2, I have shown the

evacuated vessel or bulb U having two cold plate or wing electrodes A, in electrical connection with each other and two cold grid electrodes G in electrical connection with each other. The two cold plate or wing electrodes having a circuit connection to one side or terminal of the hot electrode F, which circuit connection includes an inductance coil L and a source of current supply indicated at B, the positive side of which is connected to the cold plate or wing electrodes W and the negative side to one terminal of the hot electrode F. In this instance the circuit connection between the cold grid electrodes G, and the cold plate or wing electrodes W, includes a blocking condenser, indicated at C_2. Connected across this circuit is a variable capacity C_1, and included in said circuit is an inductance coil P, which constitutes, in the form shown, a coupling member in association with a coil S, in the antenna earth system N, E, the coupling being preferably a loose coupling. Where the apparatus is to be used for telephoning purposes the antenna has associated therewith or includes therein a microphone transmitter M. Where the apparatus is to be used for telegraphic communication a Morse telegraph key K is bridged across a portion of the inductance S. If desired the grid and plate circuit may be inductively associated with the plate and filament circuit through inductance L, as shown. It is obvious that the current supply to the hot electrode F, or to the circuit connection of cold plate or wing electrodes W, may be controlled in any suitable or convenient manner, as for instance, by the adjustable resistance R.

By reason of the arrangements above described and the ionizing of the gas in the evacuated vessel or bulb U due to the presence within said vessel of the hot or glower electrode F, and by impressing an electromotive force within the space between the cold plate or wing electrodes W and the hot electrode from the current source B, the device U, with its electrodes and their associated circuits and circuit connections as described becomes a generator of oscillating, alternating or pulsating electric currents which are impressed upon the circuit which connects the grid and plate electrodes, the frequency of which depends upon the condition of the gas within the vessel U, the spatial relation of the electrode member contained therein, the value of the electro-motive force impressed across the electrodes, and the amount of inductance and capacity in or associated with the circuit connection between the cold electrodes. This frequency may be varied by adjusting the capacity or inductance in said circuit connection.

By reason of the association of the oscillating circuit connecting the cold electrodes with the antenna earth system N E the oscillating, alternating or pulsating currents in said circuit connection are impressed upon said antenna earth system, and with a natural period of oscillation in said circuit, the same as that in said oscillating circuit. The emission of wave trains from the antenna earth system may be controlled in accordance with the telegraphic code through the telegraph key K, which acts to short circuit a portion of the inductance S. Or, if desired, the amplitude of the oscillations induced in the antenna earth system may be varied by and in accordance with sound waves falling upon the microphone transmitter M in the usual manner. It is obvious that the wave length of the emitted wave trains may be altered in a manner well understood in the art.

I am unable at the present time to give a wholly satisfactory explanation of the theory of the generator action of the apparatus. I have discovered, however, as hereinbefore stated that a system constructed as shown and described and energized from a suitable current source becomes the seat of continuous oscillations and it is my opinion that the phenomenon depends upon the inductive effect of successively applied charges or surges of potential upon the grid and plate electrodes which charges or surges have the power to affect momentarily the conductivity of the surrounding or inter-connecting gas medium within the vessel in such manner that the action, when set up, is self perpetuating.

From the foregoing description it will be observed that in its broad scope my invention lies in the discovery that when suitably connected and associated an audion becomes a generator of oscillating, alternating, or pulsating electric currents which may be utilized for any purpose for which such currents are desired, and I have succeeded in securing remarkable results in the practical use and operation of an oscillation generator of this character particularly when applied to the generator of high frequency oscillations.

It is obvious that the principles of my invention may be embodied in various arrangements and circuit connections without departure from the spirit and scope of my invention as defined in the claims, but

Having now set forth the objects and nature of my invention and circuit arrangements embodying the principles thereof, what I claim as new and useful and of my own invention, and desire to secure by Letters Patent, is—

1. The combination with an evacuated vessel, of a plurality of wing elements; a

plurality of grid elements, and a hot electrode arranged therein, a grid element being arranged between each wing element and the hot electrode.

2. An audion having a plurality of grid electrodes, a plurality of wing electrodes, and a hot electrode.

3. An audion having a plurality of grid electrodes, a plurality of wing electrodes, and a hot electrode, a grid electrode being interposed between each wing electrode and the hot electrode.

In testimony whereof I have hereunto set my hand in the presence of the subscribing witnesses, on this 21st day of December, A. D., 1915.

LEE DE FOREST.

PLAINTIFF'S EXHIBIT No. 216.

Certain Pages of Book of O. W. Richardson, entitled "The Emission of Electricity from Hot Bodies."

welded or hard soldered to platinum wires sealed into the glass bulb D. A lies on the axis of a cylindrical electrode E of metal foil, or, preferably, gauze supported by the sealed-in lead F. The tube H enables the bulb to be exhausted and sealed off or connected to the apparatus for supplying various gases, measuring the pressure, etc. The precise construction of such a bulb depends on the nature of the substance A experimented with. If A is a platinum wire then all the metal parts inside the bulb are best made entirely of platinum. The whole apparatus can then be thoroughly cleaned with boiling nitric acid and distilled water. Tungsten filaments require to be electrically welded, in an atmosphere of hydrogen, to the stout leads which may be of iron or copper. Carbon filaments have to be joined with paste as in constructing incandescent lamps. Most other materials are to be welded to the supports if possible, otherwise hard soldering may be employed. In experiments of this character it is often of the utmost importance not merely to secure the chemical purity of the materials used, but to make sure that not even the smallest traces of gases are liberated in the bulb during the course of the experiments. The best way of accomplishing this is to heat the tube D to a high temperature whilst it is exhausted by a Gaede pump, assisted by a liquid air and charcoal condenser. Meanwhile the wire A is glowed out electrically, and, in order to drive every trace of gas out of the cylindrical electrode E, it is desirable that this should be heavily bombarded by cathode rays, obtained by applying a high negative potential to A. To maintain the tube D at a high temperature without its collapsing under the external pressure during the exhaustion, it should be heated in a vacuum furnace. A suitable form of furnace may be constructed with a heavy water jacketed brass base provided with holes for the tube H and the leads B, C, and F. The holes can be made airtight with glass and seal-

FIG. 1.

ing-wax, and an additional hole for the insertion of a platinum thermometer or thermocouple is desirable. On the base rests a large cylindrical brass bell jar, the line of contact being made airtight with a rubber gasket. The brass cylinder is balanced by weights attached to ropes passing over pulleys so that it can easily be moved up and down. The furnace itself is inside the brass cylinder, and rigidly attached to it. It consists, starting from the inside, of a vertical cylinder of some non-oxidizable metal such as monel metal or nickel; this is insulated by a layer of mica, over which is a winding of nichrome strip having a suitable resistance and current-carrying capacity. Between the nichrome winding and the outer brass cylinder is a thick packing of fireclay and asbestos. The leads to the nichrome strip and the exhaust can be let in through the cover of the brass cylinder. This, as well as the brass base, should be water cooled. With such an arrangement, with the furnace exhausted to a pressure of about 1 cm., the experimental bulbs can be exhausted for several days at a temperature of about 570° C. without collapsing. A vacuum furnace of this type in actual operation is shown in Fig. 2.

Many experiments can be made without taking these elaborate precautions, but we shall see later[1] that if we wish to be sure of obtaining the effects which are characteristic of the pure metals in the absence of a gaseous atmosphere we cannot afford to dispense with the manipulation just described.

Almost all the phenomena under consideration are very sensitive to small changes in temperature; so that even when it is not necessary to know the actual temperature of the filament A it is essential that it should not vary. A very sensitive temperature control is provided by a method which involves the measurement of the resistance of the filament. For this purpose, in carrying out the experiments, the filament is made to form one arm of a Wheatstone's bridge which is actuated by the battery supplying the heating current. The arrangement of apparatus for measuring the thermionic current which flows from the filament A to the cylinder E is shown diagrammatically in Fig. 3. K, L, and M are the three other

[1] See chaps. III. and IV.

resistances which form the arms of the Wheatstone's bridge,

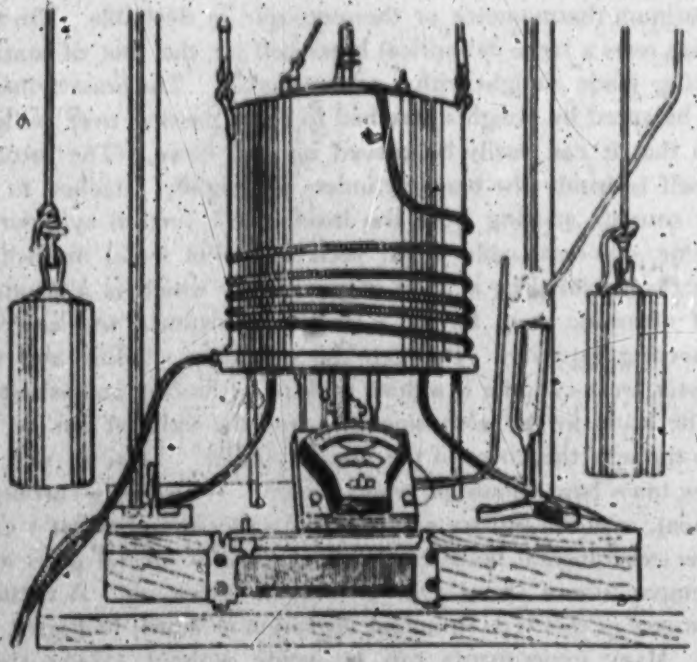


FIG. 2.

the bridge galvanometer G being provided with the key N.

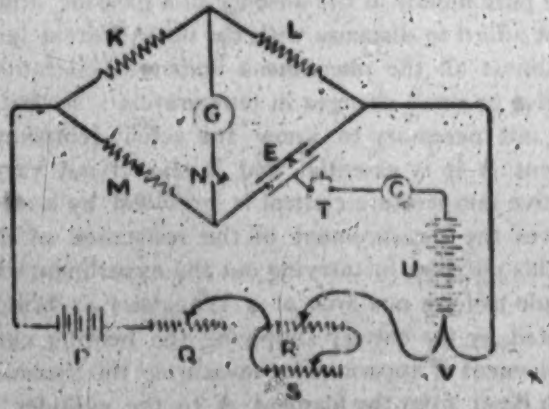


FIG. 3.

The main heating current is supplied by the battery P and

to eliminate traces of gas from apparatus containing ground glass joints; so that this type of apparatus is useful only when the effects of such traces of gas are relatively unimportant.

A convenient arrangement for making rapid qualitative tests of the sign of the ions emitted by hot wires has recently been described by Hopwood.[1] This consists in bringing an electrically-charged rod near a long loop of the electrically-heated wire which is connected to earth. The loop will only be deflected provided it does not emit ions of the sign opposite to the charge on the rod.

Relation between the Currents and Electro-motive Force and Gas Pressure.

The first experimental investigation of this question was made by McClelland[2] with an arrangement similar to Fig. 1 in its main features. In all these experiments the temperature of the filament is kept constant and the general character of the results to be described is independent of the nature of the material used, provided that the filaments have been heated for a considerable length of time (see pp. 60 and 182). At pressures comparable with atmospheric the relation between the current and the difference of potential maintained between the filament and the cylinder is similar to the left-hand half of the curve shown in Fig. 4, although this figure actually refers to another case. With low voltages the current is proportional to the applied potential difference, but as the potential difference increases, the rate of increase of the current gradually falls off until finally saturation is attained. There is thus a definite limit to the number of ions liberated by the glowing filament in unit time. In air at low temperatures this description applies only when the filament is positively charged; there is no appreciable current when the wire is charged negatively. At higher temperatures similar results are obtained whether the filament is charged positively or ne-

[1] "Phil. Mag.," Vol. XXIX, p. 362 (1915).
[2] "Camb. Phil. Proc.," Vol. XVI, p. 296 (1901).

gatively, the ratio between the saturation current with the wire negative and that with the wire positive increasing continuously with rising temperature. In these respects, the observations agree with the earlier experiments described on page 3.

With pressures of the order of 1 millimetre of mercury the current-E.M.F. curves were found to be entirely different. With the filament negatively charged there was no indication of saturation. The current in general increased more rapidly than the first power of the potential difference. The effects observed with a *positively* charged wire at these pressures are exhibited in Fig. 4, which actually refers to this case. At intermediate voltages there is evidence of saturation, but this

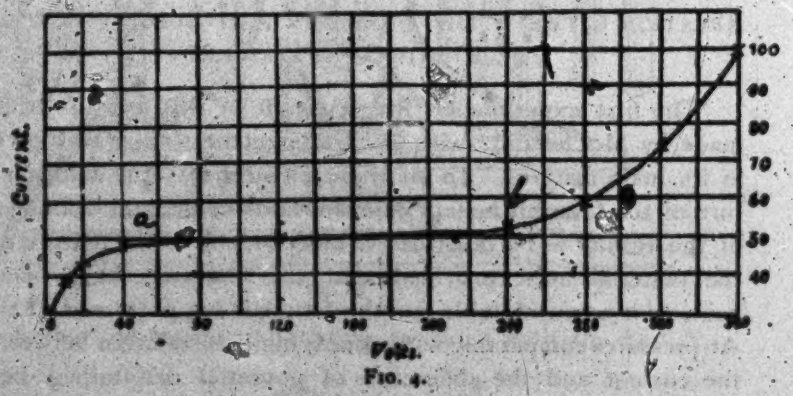


FIG. 4.

stage is succeeded by a stage in which the current again increases with rising potential difference.

McClelland showed that these phenomena could be explained in a general way on the hypothesis that the ions liberated at or near the surface of the filament were able, under the accelerating influence of the electric field, to produce new ions by impact with the neutral molecules with which they collided. In the case of the positive ions this increase in the current due to ionization by impact did not begin to make itself felt, in the example shown in Fig. 4, until there was a difference of potential of over 200 volts between the electrodes. The existence of saturation with lower potentials showed that all the ions initially liberated were being collected by the cylinder, and, as the current was independent of the

electromotive force in this region, there was no additional current depending on the energy of the impacts. The absence of saturation with the currents from the negatively charged wire makes it necessary to suppose that ionization by collision sets in before the stage at which saturation is reached. Thus the part *a*, *b* of the curve in Fig. 4 is missing when the wires are charged negatively. Another consequence of this interpretation is that ionization by impact is effective with a smaller fall of potential for negative than for positive ions. The hypothesis of ionization by impact had previously been put forward by Townsend and J. J. Thomson to account for somewhat similar phenomena exhibited by other sources of ionization. McClelland's experiments seem, however, to have first indicated definitely that positive ions could give rise to new ions by collision.

A more detailed examination of the relation between current, pressure, and electromotive force with negatively charged wires has been made by H. A. Wilson.[1] Some of the results obtained by Wilson at pressures ranging from 0·0036 mm. to 760 mm. are shown in Figs. 5 and 6. If the increase of current beyond the horizontal line corresponding to the lowest pressure (0·0036 mm.) is due to ionization by collision, Wilson showed that, according to Townsend's theory,

$$\log n_b/n_a = \frac{V}{E \log b/a}\left\{e^{-(NEpa/V)\log b/a} - e^{-(NEpb/V)\log b/a}\right\} \quad (7)$$

provided $V/pa\log b/a$ is greater than 200. In this equation n_b is the number of negative ions which reach the cylinder in unit time, n_a is the number emitted by the hot wire (of circular section) in the same time, V is the applied potential difference, p the gas pressure, b the radius of the cylinder, a that of the wire, N the number of ionizing impacts per moving ion per cm., and E the potential fall necessary to acquire the ionizing energy (ionizing potential). This formula was found to represent the experimental results satisfactorily, with N = 3·04 and E = 17·7 (volts). The values of the constants are in satisfactory agreement with those deduced by Townsend from

[1] "Phil. Trans., A.," Vol. CCII, p. 243 (1903).

experiments with ionized air at ordinary temperatures, when allowance is made for the difference in the number of mole-

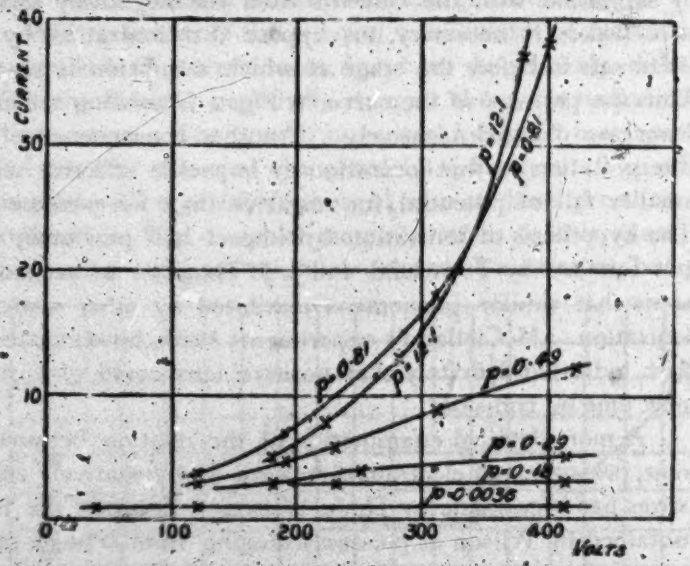


FIG. 5.

cules in unit volume of a gas at a definite pressure due to change in temperature. The results point to the rather im-

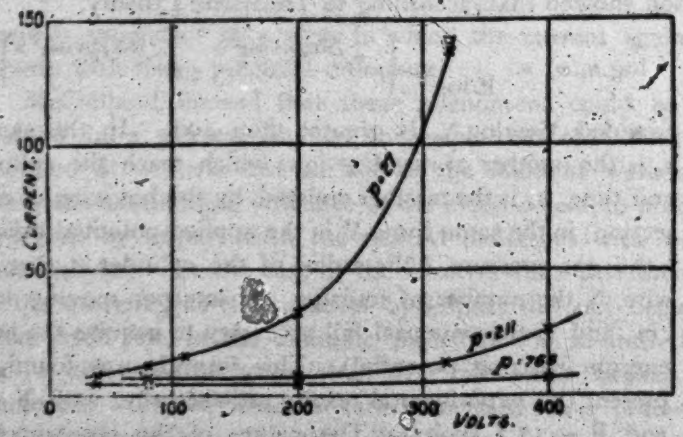


FIG. 6.

portant conclusion that ionization by impact depends solely on the nature of the molecules, and their distance apart, and has nothing directly to do with the temperature of the gas.

In this experiment the temperature must have been about the same as in the case to which Fig. 10 refers. The pressure is given as less than 0·001 mm. It will be seen that there is here no perceptible increase in the current between 25 and 180 volts.

It is only when the thermionic current densities are comparatively small that saturation is attainable with potential differences of 20 volts or under. With the large emissions which occur at very high temperatures the potential difference required for saturation may be very much higher owing to the mutual repulsion of the emitted electrons. This leads to an interesting effect which was discovered and explained by Langmuir.[1] In examining the thermionic current between two hairpin-shaped tungsten filaments, under fixed differences of potential, at various temperatures, the results exhibited in Fig. 11 were obtained. The experimental values lie along the broken curves, the continuous curve representing the saturation current at different temperatures. It will be noticed that the broken curves coincide with the continuous curve up to a certain temperature which is lower the smaller the applied potential difference. Beyond this point the currents are below the saturation value, but they still increase with increasing temperatures of the filament. At still higher temperatures the broken curves bend round, and the current under a given potential difference becomes entirely independent of the temperature of the hot filament. Owing to the mutual repulsion of the electrons a given difference of potential applied over given boundaries is only capable of forcing a definite number of electrons across the intervening space in unit time, no matter how many may be available.

In order more clearly to see how this comes about let us consider the simplest possible case, that of an emitting plane opposite a parallel conducting plane which represents the receiving electrode. Take the axis of x perpendicular to the planes and let V be the electrostatic potential at any point. Then the value of V is governed by Poisson's equation which reduces to

$$\frac{d^2V}{dx^2} = -4\pi\rho \qquad (7)$$

[1] "Phys. Rev.," Vol. II, p. 453 (1913).

ρ being the volume density of electricity at any point.

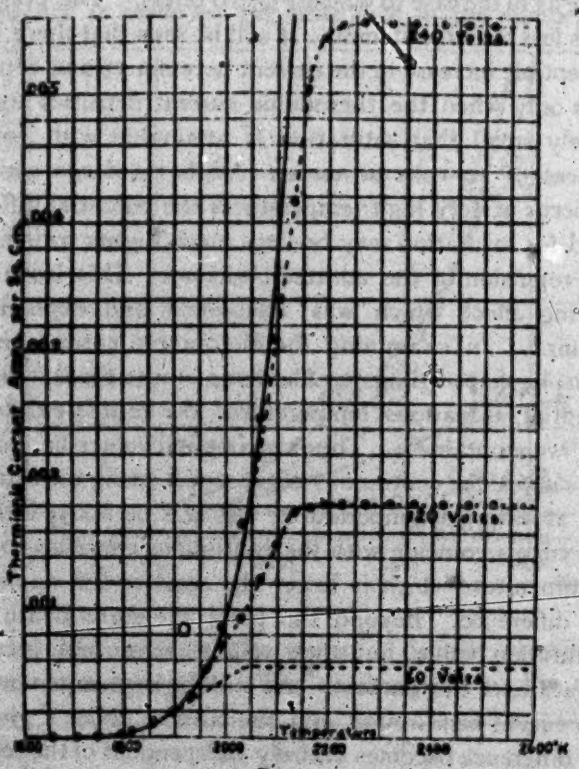


FIG. 11.

When there are no electrons emitted ρ is zero at every point, so that $\frac{dV}{dx}$ is constant and may be represented by the straight line PQT in Fig. 12. When the plate is emitting electrons these will give rise to a negative value of ρ in the space as they cross it, and if the number is small, the value of ρ thus arising will be approximately independent of x; so that the right-hand side of (7) will be a positive constant and the graph of V will be approximately parabolic and similar to PST. As the current and $-\rho$ increase this curve will sink below PQT

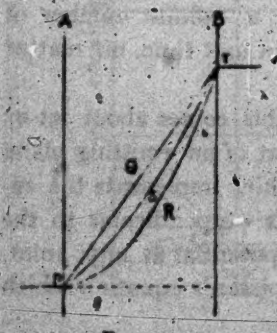


FIG. 12.

until the stage PRT is reached, where the tangent at P is horizontal. Any further increase in the supply of electrons will now have no effect on the distribution of potential between the plates because there is nothing to drag them away from AP. We here assume that the emission velocities of the electrons are small compared with those which they acquire under the influence of the field; so that the results will only be true for fairly large potential differences (see Chapter V).

Now let us see how the current will depend on the applied potential when the condition that $\frac{dV}{dx}$ vanishes at the hot plate is satisfied. Let $+\epsilon_1$ denote the numerical value of the negative charge of an electron and $+\rho_1$ the numerical value of the negative density of charge at any point. An electron at a point when the potential is V (if V = 0 at the hot plate) will have acquired an amount of kinetic energy given by the equation

$$\tfrac{1}{2}mv^2 = V\epsilon_1 \quad . \quad . \quad . \quad . \quad (8)$$

The current per unit area carried by the electrons at that point will be

$$i = v\rho_1 \quad . \quad . \quad . \quad . \quad (9)$$

and equation (7) may be written

$$\frac{d^2V}{dx^2} = 4\pi\rho_1 \quad . \quad . \quad . \quad . \quad (10)$$

By elimination of ρ and v from (8), (9), and (10)

$$\frac{d^2V}{dx^2} = 2\pi i\sqrt{\frac{2m}{\epsilon_1 V}}$$

and integrating, subject to $\frac{dV}{dx} = 0$ when V = 0,

$$\left(\frac{dV}{dx}\right)^2 = 8\pi i\sqrt{\frac{2mV}{\epsilon_1}} \quad . \quad . \quad . \quad (11)$$

By integrating again, subject to V = 0 when $x = 0$, and solving for i we find

$$i = \frac{\sqrt{2}}{9\pi}\sqrt{\frac{\epsilon_1}{m}}\frac{V^{3/2}}{x^2} \quad . \quad . \quad . \quad (12)$$

The same general method of treatment with the appropriate modification of Poisson's equation can be applied to the case of a circular wire surrounded by a coaxial cylinder, giving

$$i = \frac{2\sqrt{2}}{9}\sqrt{\frac{e_1}{m}}\frac{V^{3/2}}{r\beta^2} \qquad (13)$$

when r is the radius of the cylinder, and

$$\beta = \log\frac{r}{a} - \frac{2}{3}\left(\log\frac{r}{a}\right)^2 + \frac{11}{120}\left(\log\frac{r}{a}\right)^3 - \frac{47}{3300}\left(\log\frac{r}{a}\right)^4 + \ldots,$$

a being the radius of the wire. In fact Langmuir[1] has shown from a consideration of the dimensions of the equations that, whatever may be the geometrical relation between the emitting and receiving electrode, the current under these circumstances will be equal to $V^{3/2}$ multiplied by a factor depending on e_1/m and the geometry of the system.

It appears then that over the flat part of the broken curves in Fig. 11 the current should be proportional to $V^{3/2}$. This requirement is found to be borne out by the experimental results; so that there can be no doubt of the adequacy of the foregoing explanation. Langmuir has suggested that experiments with concentric cylinders using equation (13) could be made so as to determine the value of e_1/m with great precision.

The effect of the mutual repulsion of the electrons in preventing the attainment of saturation will be important only when the saturation currents are of considerable magnitude; with sufficiently small currents this effect will vanish. We shall see in Chapter V that the electrons are emitted, not with zero velocity, but with a distribution of velocities whose mean square is proportional to the absolute temperature of the hot body. At 2000° K. this mean velocity is comparable with that which an electron would acquire by falling through a potential difference of about 0·25 volt. At relatively low

[1] Loc. cit.

temperatures when the emission is comparatively small, if the hot body is surrounded by the receiving electrode, we should expect saturation to be attained without the application of any potential difference; since all the electrons are emitted with some velocity, and any velocity, however small, will be sufficient to carry them across to the electrode ultimately. This supposition does not accord with the facts as observed in experiments with electrically heated wires surrounded by coaxial cylindrical electrodes. Under these conditions it is the writer's experience that potential differences comparable with two or three volts are required to cause saturation even when dealing with the smallest currents which are convenient to measure. There can be very little doubt that in these cases one cause operating against the attainment of saturation is the effect of the magnetic field, due to the heating current, on the motion of the electrons.

To see how this comes about consider the case of a hot wire, of circular section and radius a, surrounded by a coaxial cylindrical electrode of radius b. Let V_1 be the potential difference in volts between the wire and the cylinder. The electric intensity R is everywhere radial and at distance r from the axis is given in electro-magnetic units by

$$R = V_1 \times 10^8/r \log b/a = A/r \quad . \quad . \quad (14)$$

The magnetic intensity H lies in circles about the axis of the wire, and, if j is the current in amperes, its value at distance r is

$$H = 2j/10r = B/r \quad . \quad . \quad . \quad (15)$$

On account of its direction the magnetic field will not affect the angular velocity of the electrons about the axis. Disregarding this rotation, the paths of the electrons are periodic curves, in the plane containing the axis, which keep intersecting the surface of the emitting cylinder. The effect of the neglected rotation is simply to convert these plane curves into spirals about the axis. There is a certain maximum distance, under given conditions, which an electron is able to travel from the axis, and unless this is equal to or greater than the radius of the outer cylinder the electrons will return to the surface of

emission and will contribute nothing to the thermionic current.

If r is the perpendicular distance of an electron from the axis, z its distance from a fixed plane perpendicular to the axis, and θ the angle the plane containing the axis and the electron makes with a fixed plane through the axis, the equations of motion of the electron are:—

$$m\frac{\partial^2 r}{\partial t^2} - mr\left(\frac{\partial\theta}{\partial t}\right)^2 = Re - He\frac{\partial z}{\partial t} = \frac{Ae}{r} - \frac{Be}{r}\frac{\partial z}{\partial t} \quad . \quad (16)$$

$$m\frac{\partial^2 z}{\partial t^2} = He\frac{\partial r}{\partial t} = \frac{Be}{r}\frac{\partial r}{\partial t} \quad . \quad (17)$$

$$\frac{\partial}{\partial t}\left(r^2\frac{\partial\theta}{\partial t}\right) = 0 \quad . \quad (18)$$

From (18)

$$\frac{\partial\theta}{\partial t} = \frac{a^2}{r^2}\dot{\theta}_0, \quad . \quad (19)$$

if $\frac{\partial\theta}{\partial t} = \dot{\theta}_0$ when $r = a$.

From (17)

$$\frac{\partial z}{\partial t} = \dot{z}_0 + \frac{Be}{m}\log\frac{r}{a} \quad . \quad (20)$$

if $\frac{\partial z}{\partial t} = \dot{z}_0$ when $r = a$.

Substituting these values of $\frac{\partial\theta}{\partial t}$ and $\frac{\partial z}{\partial t}$ in (16) and integrating subject to

$$\frac{\partial r}{\partial t} = \dot{r}_0 \text{ when } r = a,$$

$$\frac{\partial r}{\partial t} = \left[\dot{r}_0^2 + a^2\dot{\theta}_0^2\left(1 - \frac{a^2}{r^2}\right) - \frac{B^2e^2}{m^2}\left(\log\frac{r}{a}\right)^2 + \frac{2(Ae - Be\dot{z}_0)}{m}\log\frac{r}{a}\right]^{1/2} \quad . \quad (21)$$

The maximum value r_m of r is given by $\frac{\partial r}{\partial t} = 0$ or from (21), after substituting the values of A and B in terms of V_1 and f, by

$$V_1 = 10^{-8} \log \frac{b}{a}\left[\frac{j^2 e}{50m} \log \frac{r_m}{a} + \frac{j}{5}\dot{z}_0 - \frac{m\dot{r}_0^2 + ma^2\dot{\theta}_0^2\left(1 - \frac{a^2}{r_m^2}\right)}{2e \log r_m/a}\right] \quad (22)$$

Thus if r_m is to be just equal to the radius b of the outer cylinder,

$$V_1 = 10^{-8} \log \frac{b}{a}\left\{\frac{j^2 e}{50m} \log \frac{b}{a} + \frac{j}{5}\dot{z}_0 - \frac{m\dot{r}_0^2 + ma^2\dot{\theta}_0^2\left(1 - \frac{a^2}{b^2}\right)}{2e \log b/a}\right\} \quad (23)$$

If V_1 has a value equal to or greater than this the electrons will reach the electrode and form part of the current, otherwise they will not do so. If j is very small the right-hand side of (23) is negative, indicating that the current will be able to flow against an opposing potential owing to the initial emission velocities. The point of immediate interest, however, is the first term, on the right-hand side of (23), which is always positive and is independent of the emission velocities. This shows that owing to the action of the magnetic field due to the heating current, a definite potential is necessary in order to drag the electrons across to the electrode. With thin wires, which require only a small current to heat them, this potential difference is unimportant. Thus if $b/a = 200$ and $j = 1$ ampere, V_1 is only about 0·2 volt. On the other hand, with thick wires, which require large heating currents, the necessary values of V_1 may be quite large.

Another important factor which has to be taken into account, especially with thin wires, is the drop of potential along the wire due to the flow of the heating current. This is usually comparable with 1 volt per cm. In order to ensure that no part of the wire is at a positive potential compared with the cylinder, it is necessary that the *positive* end of the wire should be at a potential at least as low as that of the cylinder. If the potentials are applied at the negative end of the wire, it will appear from this cause alone that an additional negative

potential equal to the fall along the hot wire has to be applied in order to ensure complete saturation.

That the mutual repulsion of the electrons, the magnetic field due to the heating current, and the drop of potential along the wire, also due to the last-named cause, are the chief general factors which prevent the attainment of saturation is strikingly shown by some recent experiments by Schottky.[1] Using concentric cylinders the thermionic currents with small differences of potential, both accelerating and retarding, were measured under conditions such that the heating current was cut out at the instant of measurement. By means of a suitable in-and-out switch, operating continuously, matters were arranged so that no appreciable variation in the temperature of the wire ensued thereby. Under these conditions the drop of potential along the filament and the magnetic field due to the heating current are eliminated, and it was found that the current saturated at zero potential difference; except for an effect, which was smaller the lower the temperature and smaller the current, arising from the mutual repulsion of the emitted electrons. In determining the actual difference of potential between the wire and the electrode, it was found necessary to add to the apparent applied potential difference registered by the voltmeter, a difference of potential equal to the contact potential between the two metals used. Thus experiments of this kind can be used to measure contact differences of potential under good vacuum conditions without displacing the surfaces subject to test.

Schlichter,[2] by using methods of heating the electrode which do not involve the passage of an electric current through it, has been able to show that the electron current with 220 volts driving potential is only about 10-20 per cent greater than that under zero potential difference, when the hot metal has been thoroughly glowed out. The special conditions which affect the attainment of saturation in the case of freshly heated metals will be referred to again on page 182, Chap. VI.

[1] "Ann. der Phys.," Vol. XLIV, p. 1011 (1914).
[2] *Ibid.*, Vol. XLVII, p. 373 (1915).

causes which might give rise to the observed effects. No doubt these are partly caused by electrons and ions emitted by the hot surfaces on account of the high temperature, but they may also be due partly to ions emitted by chemical action. The actions are also greatly complicated by the presence of the hot vapours which must have properties similar to those of flames.

The Relative Importance of Various Factors in Causing the Emission of Electrons from Hot Bodies.

We have already considered three possible causes of electronic emission, namely: the escape of the electrons owing to the purely thermal increase of their kinetic energy (p. 27), the liberation of electrons as one of the products of chemical action (p. 49), and the complete photoelectric emission (p. 95). We have seen (p. 100) that the available photoelectric data indicate that the last of these is too small to account for the emissions which have been observed from hot bodies; so that unless and until fresh observations are made which tend to conflict with this conclusion, it does not appear necessary to consider this particular question further.

It remains to deal with the relative claims of the purely thermal effect and of chemical action. In the last few years a number of writers have advocated the view that all the observed effects are attributable to chemical action. The case for this position is, briefly, as follows:—

We have seen in Chapter II that any electronic emission arising from chemical action would be likely to follow a law of temperature variation practically identical with that required by the purely thermal effect; so that the fact that the theoretical law is satisfied by the experimental results offers no criterion for distinguishing between the two views. In certain cases there is some evidence that electrons are liberated as a direct result of chemical action between solids and gases. The experiments of Haber and Just[1] have shown that when the alkali metals, their alloys, or amalgams, are attacked by oxygen,

[1] "Ann. der Physik," Vol. XXXVI, p. 308 (1911).

hydrochloric acid gas, phosgene gas, water vapour, and certain other chemically active gases or vapours, electrons are liberated in considerable quantity. It may be urged (cf. Chapter IX, p. 290) that in reality this also is a thermal emission, caused by a local increase of temperature in the surface layer arising from the heating caused by the chemical action. Most of Haber and Just's experiments were made with drops of various amalgams and with the liquid alloy of sodium and potassium. From a determination of the amount of chemical action occurring they calculate that in a particular experiment the heat generated by the chemical action was not sufficient to raise the temperature of the whole of a drop more than 2° C. But it is clear that the temperature of the surface layers must have been raised to a very much greater extent, and as it is only the temperature of the surface layer which is of any account if the effect is a purely thermal one, it cannot be said that the experiments so far made by these authors prove that the emission is a direct consequence of chemical action. Similar conclusions to those of Haber and Just have been reached by Fredenhagen,[1] who has shown that the emission ordinarily observed when the alkali metals are heated can be reduced to very much smaller values by the careful elimination of gases. The smallest currents recorded by Fredenhagen are, however, not smaller than those calculated[2] by an application of the considerations on p. 40 to the known emission from platinum or tungsten, in spite of the strong electropositive character of the alkali metals. The large values are restored, at least partially, when small quantities of gases, and especially of oxygen, are allowed to come in contact with the metal. But when one remembers the extraordinary sensitiveness of the emission to changes of temperature and that, in any event, the effect is a purely superficial one, it is questionable whether the observed enhancement of the emission may not be due to the local increase of temperature caused indirectly by the chemical action. It is, of course, abundantly proved that an emission is caused by chemical action in these cases, but it is extremely difficult to

[1] "Verh. der Deutsch. Physik. Ges.," Jahrg. 14, p. 386 (1912).
[2] Cf. O. W. Richardson, "Phil. Mag.," Vol. XXIV, p. 742 (1912).

be sure that the effect is the direct result of the chemical action and is not caused indirectly by the heat generated at the surface. (See, however, p. 296.)

The remaining cases which have been cited as examples of the emission of electrons by chemical action are the oxidation of calcium and the emission from incandescent carbon. Fredenhagen[1] has put forward the view that the activity of the lime-covered cathode is caused by the recombination of the calcium and oxygen which are separated by electrolysis during the passage of the current. The arguments in favour of this view have already been dealt with on p. 85 where they were not found to resist a critical examination successfully. We have already seen (p. 86) that Horton, who made a direct test of the question, was unable to detect any emission from calcium arising directly from oxidation. Wehnelt,[2] who has devoted much attention to the lime-covered cathode, has recently expressed the opinion that in the case of this material there is no evidence which would favour a chemical rather than a purely thermal cause for the origin of the emission. Finally, Germershausen[3] has shown that the emission from lime is increased by the removal of every trace of gas from its surroundings. Under these conditions the discharge becomes very similar to that from tungsten as observed by the writer and by Langmuir.

The emission from carbon has been attributed to chemical action between the carbon and traces of gaseous contamination by Pring and Parker,[4] and by Pring.[5] Using comparatively large rods of carefully purified carbon they found that the negative discharge to a small electrode in the neighbourhood of the rod diminished progressively as the gases were removed from the rod by continuous heating. The currents finally obtained at the highest temperatures were very much smaller than those recorded by other observers with carbon (see

[1] "Leipziger Ber.," Vol. LXV, p. 42 (1913).
[2] "Physik. Zeits.," Jahrg. 15, p. 558 (1914).
[3] *Ibid.*, Jahrg. 16, p. 104 (1915).
[4] "Phil. Mag.," Vol. XXIII, p. 192 (1912).
[5] "Roy. Soc. Proc., A.," Vol. LXXXIX, p. 344 (1913).

pp. 69 and 75). An application[1] of the considerations developed on p. 65, however, shows that the magnitude of the heating currents and the geometrical arrangement of the apparatus used by these authors were such that no electrons at all would be able to reach the electrode at the higher temperatures. Thus there is no difficulty in accounting for the smallness of the observed currents on the purely thermal theory of the emission. The only difficulty, which is present on any theory of the origin of the electrons, is to explain why the observed currents were not actually zero. The small currents can be accounted for[2] if it is supposed either that traces of gas present interfere with the motion of the electrons or that some of the electrons combine with uncharged molecules or atoms of the gas to form negative ions whose motion is almost unaffected by the magnetic field. Either of these assumptions would explain the fact that the observed currents are increased by the admission of traces of various gases. The relatively large effects produced by very small amounts of gas are in favour of the second hypothesis, which also explains the relative efficiency in this respect of the various gases tested. Another factor which would tend to make the currents observed in these experiments too small is the effect of the mutual repulsion of the electrons considered by Langmuir (see p. 61). Moreover, the results of the experiments are in complete disagreement with the results of experiments made with well-glowed-out carbon filaments by Deininger[3] in 1908, and of the more recent experiments of the writer and of Langmuir. In the last two cases the precautions described on p. 14 were taken in preparing the bulbs, and although it is not claimed that every trace of gas was got out of this very difficult substance, the conditions were much better in this respect than in the experiments of Pring and of Pring and Parker. The same claim can almost certainly be made for Deininger's work. In fact, it is quite impossible to attain good vacuum conditions with the large quantities of hot

[1] O. W. Richardson, "Roy. Soc. Proc., A.," Vol. XC, p. 174 (1914).

[2] Loc. cit.

[3] "Ann. der Physik," Vol. XXV, p. 285 (1908).

material used by Pring. Taking all the facts into consideration they appear to the writer to afford no support to the contention that the emission from carbon has anything whatever to do with chemical action. It may be that such a chemical effect exists, but its existence is not demonstrable, or even rendered probable, by the evidence which has been submitted.

Thus there is no case in which it has been established with certainty that chemical action is the direct and immediate cause of an emission of *electrons*. The majority of chemical actions between solids and gases certainly do not give rise to electrical effects of this kind to any appreciable extent (see Chap. IX). The only case in which the evidence renders the occurrence of electron emission as a chemical effect probable is that of the alkali metals. The experiments of Haber and Just and of Fredenhagen do, on the whole, indicate a balance of probability in favour of a direct chemical effect in this case, although, in the judgment of the writer, they cannot be held to establish it with certainty.

The advocates of the chemical point of view have held that the emissions usually observed are due to actions between the hot metal and minute traces of residual gas and not to chemical actions on any considerable scale. In support of this it may be urged that, as the effect is a purely superficial one, a small quantity of gas will exert as large an effect as a greater amount, down to a certain limit. On the other hand, it cannot be said that a comparison of the specific effects of different gases lends any support to the chemical theories. In the case of platinum, the only gas which causes any considerable increase in the emission is hydrogen, and although there is probably some chemical combination in this case it certainly is not of a violent character. In the case of tungsten all gases which act chemically on the metal have been found to reduce the emission and not to increase it.

The difficulty, discussed on pp. 71 *et seq.*, of determining the precise values of the constants A and b, and the dependence generally of the emission on factors which are difficult to control and to specify, has been held to favour the view that these effects are caused by the interaction between the hot

bodies and traces of gaseous contamination of uncertain composition. It would, however, seem more reasonable to attribute these features of the phenomenon to the fact that it is of an entirely superficial character and is very sensitive to changes in the nature or composition of the surfaces. For example, the admission of oxygen will coat the hot metal with a layer of oxide. If, as appears to be the case with calcium, the oxide is more active thermionically than the metal, the emission in presence of oxygen will exceed the normal value. If the oxide is inactive its presence will tend to prevent the electrons escaping from the metal and will thus reduce the emission. The effect of oxygen on tungsten is probably of this nature. Minute traces of gas would be sufficient to produce effects of this kind, and if the composition of the gas were uncertain and variable the effects would be correspondingly so. A similar difficulty arises in other superficial phenomena, such as the photoelectric effect, surface tension, and optical reflexion, although, as a rule, it is not so marked. This is on account of the extreme sensitiveness of the thermionic emission to small changes in the work required for an electron to escape. There is, in fact, no comprehensive body of evidence supporting the view that interaction with gases is an invariable and direct cause of thermionic emission; the evidence that gases act indirectly by modifying the quantity of the emission quite generally is of a much stronger character. In this connexion the close relationship between electron emission and contact potential difference, which is required on theoretical grounds, and the sensitiveness of both these phenomena to superficial contamination, should also be kept in mind.

Experiments made by the writer[1] have shown that the emission from tungsten in a good vacuum is a property of the element itself, and cannot be attributed to chemical or other secondary actions between the tungsten and traces of other contaminating material. The advantages of tungsten in investigations of this character have been alluded to already (p. 117). The tests were made with experimental tungsten

[1] "Phil. Mag.," Vol. XXVI, p. 345 (1913).

lamps carrying a vertical filament of ductile tungsten which passed axially down a concentric cylindrical electrode of copper gauze or foil. The tungsten filaments were welded electrically in a hydrogen atmosphere to stout metal leads. These in turn were silver-soldered to platinum wires sealed into the glass container. The lead to the copper electrodes was sealed into the glass in the same way. The lamps were exhausted with a Gaede pump for several hours. During this time they were maintained at 550° to 570° C. by means of the vacuum furnace described in Chapter I. The duration of this exhaustion varied from 8 to 24 hours with different bulbs. It was continued until the apparent evolution of gas was very small and practically constant. This small final development of gas, which appeared to persist indefinitely, is believed to be due to the dissociation of the glass walls of the tube and to the diffusion through them of gases from the vacuum furnace which could only be exhausted to about 1 cm. pressure. The exhaustion was completed by means of liquid air and charcoal, the tungsten filament meanwhile being glowed out by means of an electric current at over 2200° C. Most of the tests were made after the furnace had been opened up and the lamps allowed to cool off. This treatment has been found completely to stop the emission, under the relatively slight heating caused by the radiation from the hot filament, of gases from the walls of the tubes and from the cold electrodes which had previously formed such a persistent source of difficulty in experiments with hot wires.

Although the filaments used were quite thin (about 0·007 cm. diameter), these lamps were found capable of being run so as to give thermionic currents of about 0·1 ampere for hours. Tests were made covering the following alternative possible causes of the emission:—

(1). That the emission is caused by the evolution of gas from the filaments.

In one experiment the tube was shut off by a mercury trap and the gases allowed to accumulate. The filament gave an electronic current of 0·50 ampere continuously for 30 minutes. The pressure of the gas which had accumulated was less than

10^{-7} mm. and was too small to measure. Taking into account the volume of the bulb, these figures show that for every molecule of gas evolved $2{\cdot}6 \times 10^{9}$ electrons were emitted. No conceivable process could cause so many electrons to arise from each gas molecule.

(2) That the emission is caused by chemical action or some other cause depending on impacts between the gas molecules and the filaments.

If for purposes of computation we consider the gas to be hydrogen, which is the most unfavourable assumption, since this gas makes most collisions, the data of the last experiment show that 15,000 electrons would have to arise every time a molecule impinged on the filament. This number is of course quite prohibitive. Moreover, in certain other experiments quite appreciable changes in the gas pressure caused no change in the emission.

(3) That the emission is a result of some process involving consumption of the tungsten.

In these experiments there is a loss of tungsten from the filament which is believed to be due to evaporation. The loss was determined by measuring the change in the resistance of the filament. At the same time the thermionic current was measured, giving the number of electrons emitted. In one experiment it was found that for each atom of tungsten lost 984,000 electrons were emitted. In this case the mass of the electrons emitted was *three times* the mass of tungsten lost. This experiment and others similar to it show conclusively that the emitted electrons must have flowed into the tungsten from outside points of the circuit.

(4) That the emission is caused by interaction with some condensible vapour which does not affect the McLeod gauge.

This explanation is cut out by the fact that the currents are not affected when the tube is cut off from the liquid air and charcoal and the hypothetical vapours allowed to accumulate.

These experiments have not been accepted as conclusive by Fredenhagen[1] and by Horton[2] on the ground that they

[1] "Phys. Zeits.," Jahrg. 15, p. 79 (1914).
[2] "Phil. Trans., A.," Vol. CCXIV, p. 278 (1914).

still leave open the possibility that the emission is due to interaction with the tungsten of some substance present in the filaments. In regard to this suggestion it is to be remembered that the assumption of the presence of foreign substances in the filament is a pure hypothesis. It is very unlikely that any gaseous substance, and most substances are gaseous under these conditions, could remain in a thin filament kept at over 2200° C. in a vacuum of 10^{-6} mm. pressure for a long time. The behaviour of the filaments during the experiments is distinctly opposed to this suggestion. When they are first glowed out there is a considerable evolution of gas lasting for a few seconds, and after that nothing. When the filaments are sealed in a small closed tube and allowed to disintegrate through overrunning no gas is evolved. There is good evidence that the small quantities of gas which occasionally appear in experiments of this kind come from the walls of the tube and the relatively heavy parts of the metal electrodes owing to inadequate preliminary treatment. The only impurities which would seem to have any chance of remaining in the filaments during these experiments are the highly refractory elements such as molybdenum, tantalum, carbon, thorium, etc. Even these would be expected gradually to disappear, and *there is no evidence of any progressive change in the emission at constant temperature* with properly prepared tubes. In any event it is questionable whether their presence would help the chemical theory, which would then be reduced to the position of admitting the existence of an emission from alloys but not from the pure metals. That the emission cannot be attributed to the commoner gases is also shown conclusively by the experiments (see p. 125) of Langmuir, who found that they all reduced the emission, except the inert gases which left it unaltered.

These experiments with tungsten definitely exclude chemical action as the cause of the emission from this substance. Such, at least, is the considered judgment of the writer. Although equally searching tests have not been made with other materials, a general survey of the phenomena does not indicate any definite connexion with chemical action, certainly

n the case of the refractory elements. This is supported by he results of Langmuir,[1] who finds that with tantalum, nolybdenum, carbon, and platinum as well as tungsten, the mission is increased with progressive elimination of gaseous ontamination and corresponding freedom from liability to hemical action. There is, of course, no compelling reason o expect a purely thermal origin for the effect in all cases. t may be that in the case of the alkali metals such effects as ave been observed are due entirely or chiefly to chemical ction; but this has not yet been proved, certainly not with nything like the thoroughness of proof of the contrary proosition in the case of tungsten. If the emission is ever aused by chemical action we should expect this type of ffect to be exhibited by the alkali metals, where the reactions re much more vigorous than with the refractory elements, as shown by the very much greater heat liberation per gram quivalent.

There is another argument, to which great weight should e attached, which is definitely against a chemical origin of he effects exhibited by the refractory elements. We have een that the variation of the emission with temperature enbles us to form an estimate of the energy change associated ith the liberation of one electron. We shall see in the next hapter that more direct methods are available for determing this quantity, both from the absorption of heat when elecrons are emitted, and from the liberation of heat when electrons re absorbed. All three methods give consistent results, and how that the quantity in question is very considerable.

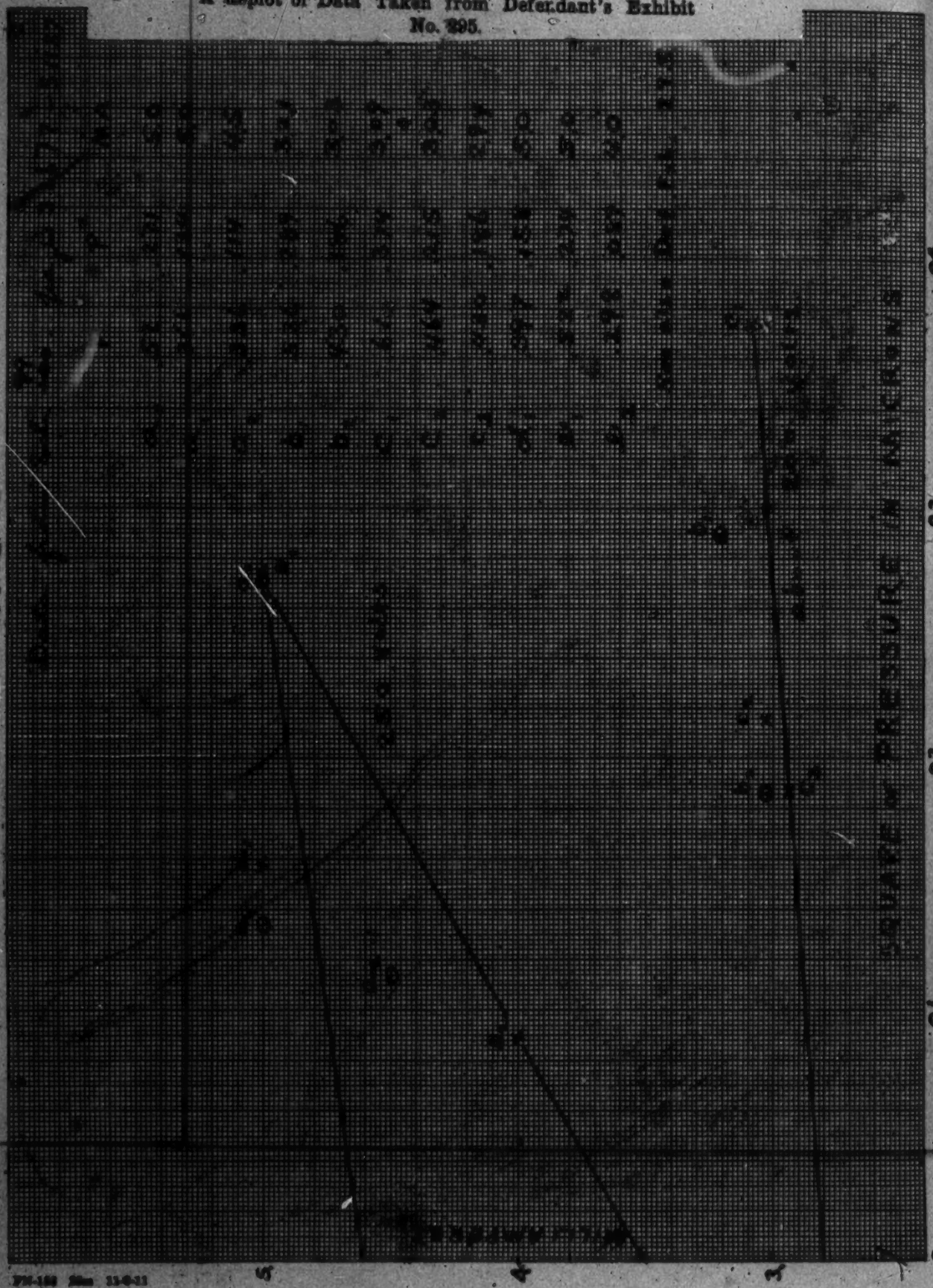
If we compare this heat change per gram equivalent of lectrons, with the heat liberated per gram equivalent in varius chemical reactions, we find, in the case of tungsten or latinum, that it is about equal to the corresponding quantity or the most vigorous chemical actions known, such as the ombination of the alkali metals with the haloids, and is far reater than the heat of any known reaction of the elements nder consideration. Thus the rate of variation of the emision with temperature is right for the physical theory of the

[1] "Phys. Rev.," Vol. II, p. 484 (1913).

phenomena, but is wrong, so far as we can judge, for the chemical theory. It is desirable at present to restrict this argument to the more refractory elements which are less active chemically, as the thermionic data for the more electropositive elements cannot be considered to be known with sufficient definiteness.

PLAINTIFF'S EXHIBIT No. 219-A.

A Replot of Data Taken from Defendant's Exhibit No. 295.

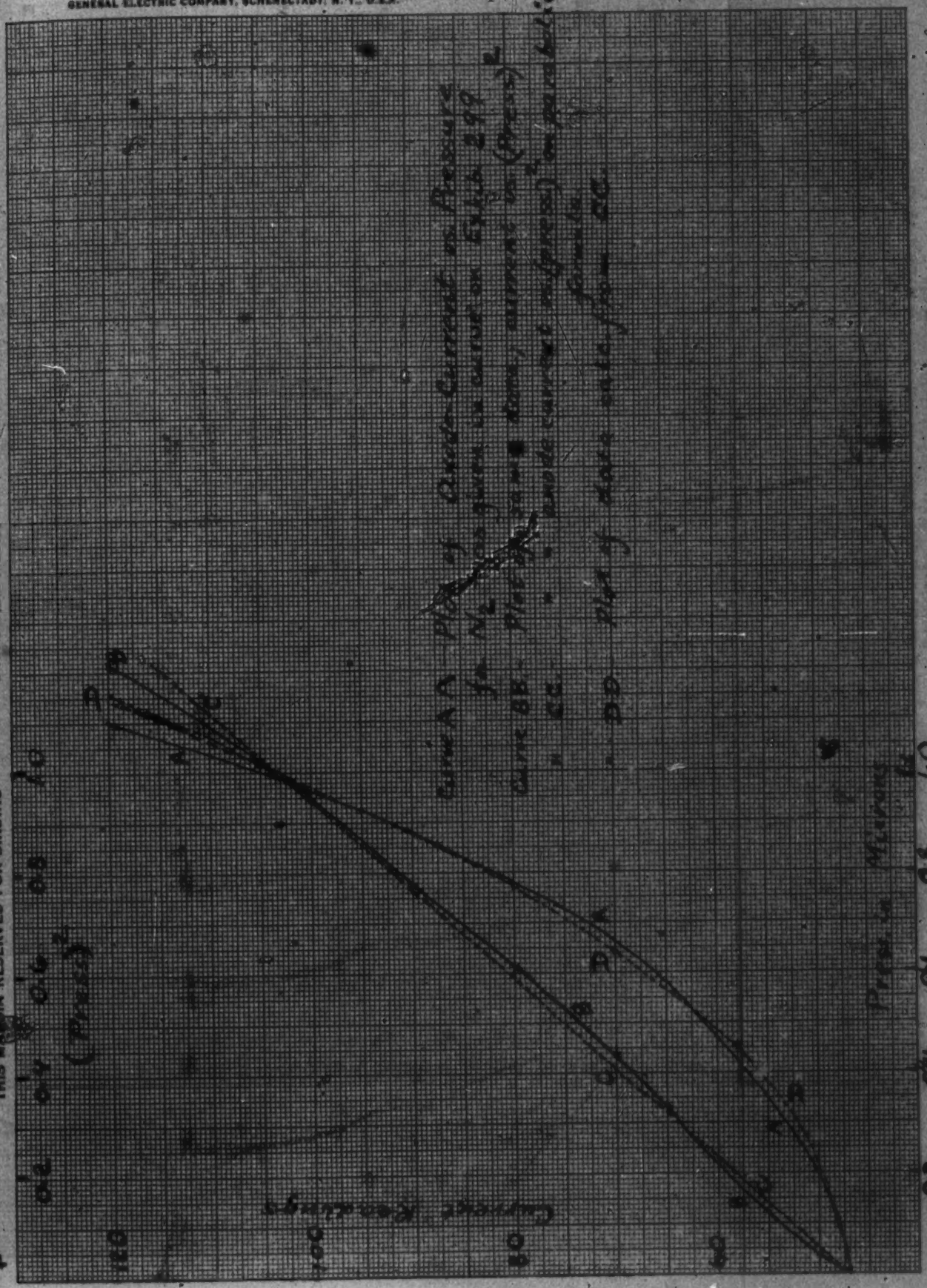


PLAINTIFF'S EXHIBIT No. 219-B.

Parabolic Plots of Currents Taken from Defendant's Exhibit No. 299.

GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., U.S.A.

219-B



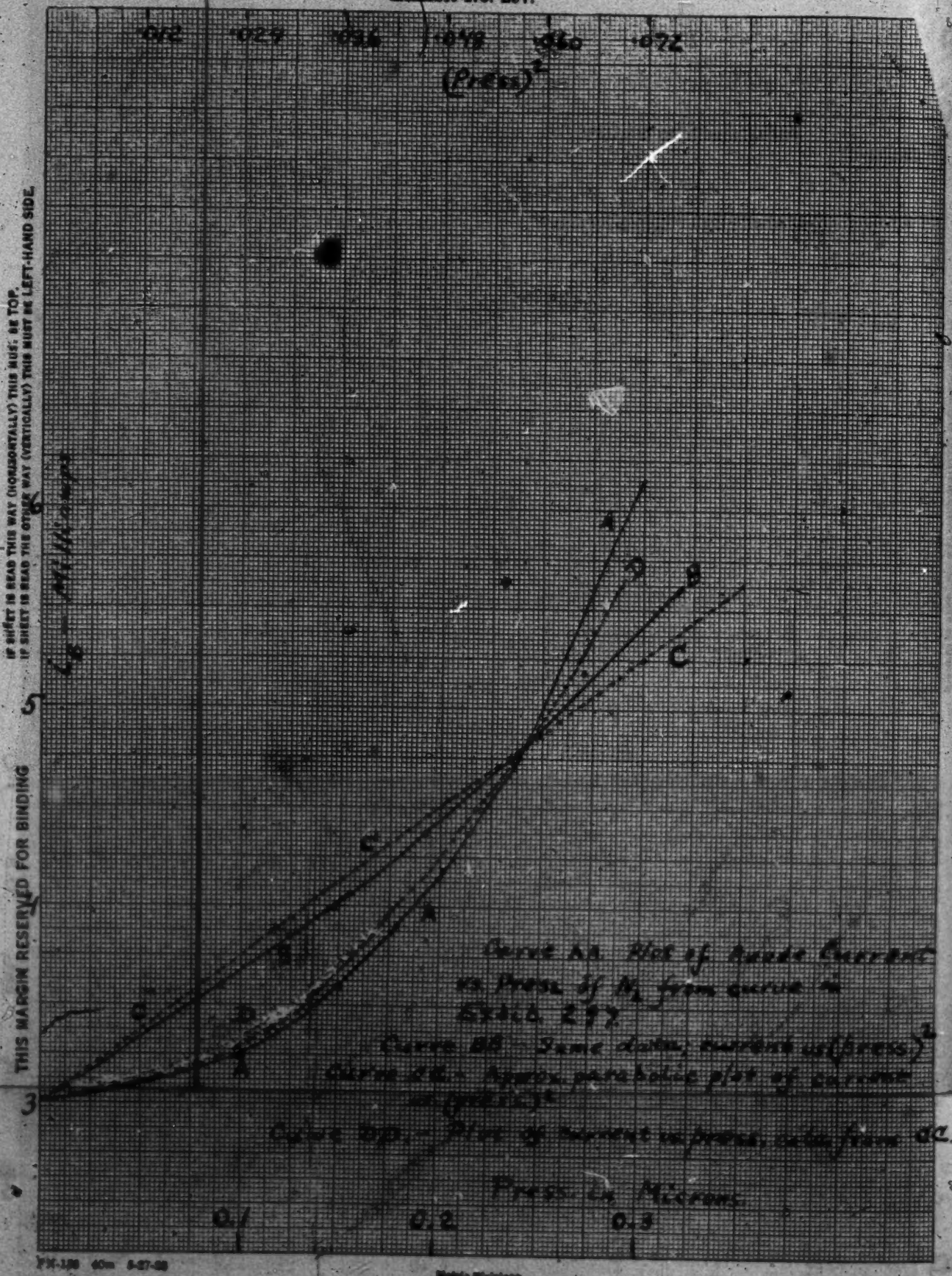
IF SHEET IS READ THIS WAY (HORIZONTALLY) THIS EDGE SHOULD BE TOP.
IF SHEET IS READ THE OTHER WAY (VERTICALLY) THIS EDGE SHOULD BE LEFT-HAND SIDE.
THIS MARGIN RESERVED FOR BINDING

B

PN 156 40m 5-27-26 — Metric Divisions

PLAINTIFF'S EXHIBIT No. 219-C.

Parabolic Plot of Currents Taken from Defendant's Exhibit No. 297.



ARGI

PLAINTIFF'S EXHIBIT No. 220.

Logarithmic Current Voltage Curve for Different Pressures of Nitrogen.